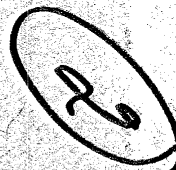


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TECHNICAL DEPARTMENT

REPORT ON FEASIBILITY STUDY FOR THE  
OPTICAL SYSTEM OF [Redacted] ZOOM STEREO COMPARATOR

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REPORT ON FEASIBILITY STUDY FOR THE  
OPTICAL SYSTEM OF [ ] ZOOM STEREO COMPARATOR

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[ ] Purchase Order No.16523)  
 (Procurement Specification - 684-01C)

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(1) Aperture requirements at different magnifications

The Specification calls for a range of magnifications to vary continuously from x10 to x200. At the high magnification a linear resolving power of 1000 lines/m.m. is desired. This determines the minimum size of aperture for the high magnification position.

Let  $N$  = number of lines per m.m., and put

$$s = \frac{\lambda}{n \sin \alpha} N \quad (1)$$

for the reduced spatial frequency corresponding to  $N$ . In (1)

$\lambda$  is the wavelength in question,  $n$  the refractive index of the object space and  $\alpha$  the angular radius of aperture of pencils in the object space. The limit of resolution occurs when  $s = 2$ , that is when the line-spacing,  $\xi_o = \frac{1}{N_o}$ , has the value

$$\xi_o = \frac{0.5 \lambda}{n \sin \alpha} \quad (2)$$

which is the classical resolution limit.

For an incoherently illuminated object, the contrast rendition in the image is determined by the contrast transfer function. For a perfectly corrected system, the contrast transfer function, defined for each spatial frequency  $s$  by

$$T(s) = \frac{\text{image contrast}}{\text{object contrast}} \quad (3)$$

decreases monotonically to zero as  $s$  increases from 0 to 2.

For  $s = 1$ , the value of  $T(s) = 0.4$ ; and  $T(s)$  is zero at, and sensibly zero near to, the limit of resolution  $s = 2$ . For this reason, even with an exceptionally well-corrected system it is desirable to use  $s = 1$  as the working limit of resolution, rather than  $s = 2$ .

For  $N = 1000$  line-pairs per m.m.,  $\lambda = 0.5 \mu$  and  $n = 1$ , the value  $s = 1$  used in (1) gives

$$\sin \alpha = 0.5 \quad (4)$$

which gives the numerical aperture necessary for resolution of 1000 lines/m.m. This is the resolution required at a magnification of x200.

The magnification of a visual instrument is conventionally taken to be the linear magnification between object and image when the image is arranged to be viewed in focus at a distance of 250 m.m. from the observer. With  $M = 200$ , the observer thus sees 1000 lines/m.m. in the object as an image having 5 lines/m.m. appearing at a distance of 250 m.m. The width of each line is thus 0.1 m.m., which subtends an angle

$$\beta = \frac{0.1}{250} = 0.0004 \text{ radians} \quad (5)$$

This value of  $\beta$ , equal to 1.3 arc minutes, is almost at the limit of visual acuity of good observers under optimum conditions. This conclusion is in accordance with experience in microscopy, where the useful magnification is accepted to be of the order of 1000 times the numerical aperture. A value of  $\sin \alpha = 0.20$  would thus normally be regarded as sufficient for a magnification  $M = 200$ .

A numerical aperture  $\sin \alpha = 0.5$  has been used in the present design study. Although this extends the performance requirements, it has been felt that the added light grasp of such a system will be a needed advantage with higher density film observed with a complex optical system having inevitable light losses.

If the same considerations as above are applied to the low magnification position, when  $M = \frac{200}{20} = 10$ , the number of lines/m.m. corresponding to  $s = 1$  and the numerical aperture are given by

$$N = \frac{1000}{20} = 50 \text{ lines/m.m.} \quad (6)$$

$$\sin \alpha = \frac{0.5}{20} = 0.025 \quad (7)$$

The spatial frequency  $N = 50$  is less than that stipulated in the specification, which calls for 80 lines/m.m. when  $M = 10$ . This requirement does not seem to be compatible with the considerations of visual acuity outlined above. This is one reason why the value (6), namely  $N = 50$  lines/m.m., has been adopted for the design study. It may be noted that  $N = 80$  lines/m.m. would correspond to a reduced spatial frequency  $s = 1.6$ , which is still within the resolved bandwidth of a system having  $\sin \alpha = 0.025$ .

Two further factors also indicated the use of the values (6) and (7) in place of the requirement of the Specification. If a zoom system is required to produce an image of constant size and level of illumination, the product of aperture and radius of object must remain constant. Thus, for a zoom ratio of 20:1, the aperture must reduce 20 times while the radius of field will increase 20 times. The values of  $N$  and  $\sin \alpha$  given in (6) and (7) are thus consistent with (a) the resolution limit being a given fraction of the overall image size, and (b) the level of illumination of the image remaining constant during zooming.

A final, and important, point is that a performance based on 1000 lines/m.m. at x200 and 50 lines/m.m. at x10 is already very exacting as regards optical design. For reasons discussed later it is unlikely that even these figures can be achieved with the theoretically possible contrast of 0.40 in the image. It should be noted that contrast is defined here as the modulation of a sine-wave of intensity. That is

$$\text{contrast} = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}} \quad (8)$$

where  $I_{\max}$  and  $I_{\min}$  are the maxima and minima of intensity respectively.

(2) Ranges of magnification, field sizes and apertures

The Specification calls for a continuous range of magnifications from x10 to x200. This can be achieved in one continuous zoom, without switching, using the system described later in this Report.

The image presented to the eye is required to have an angular size not less than  $35^\circ$ . The radius of this image, when focused at a distance of 250 m.m., is thus

$$\eta'_{\min} = 250 \times \tan 17.5^\circ = 78.8 \text{ m.m.} \quad (9)$$

In the design study the image radius has been chosen to be

$$\eta' = 100 \text{ m.m.} \quad (10)$$

giving a 25% increase over the minimum acceptable value.

At magnifications of x200 and x10 respectively, (10) gives for the radius of the object field:

$$(\eta)_{x200} = 0.5 \text{ m.m.} \quad (11)$$

$$(\eta)_{x10} = 10.0 \text{ m.m.} \quad (12)$$

Again these field sizes appear to be achievable with the system studied.

In accordance with the arguments set out in Section (1) above, the values of aperture chosen are:

$$(\sin \alpha)_{x200} = 0.500 \quad (13)$$

$$(\sin \alpha)_{x10} = 0.025 \quad (14)$$

The pencils accepted from the object thus have relative aperture decreasing from  $F/1$  at  $M = 200$  to  $F/20$  at  $M = 10$ .

As the zoom is operated, the image radius  $\eta'$  remains constant while the object size  $\eta$  <sup>decreases</sup> ~~increases~~, and the aperture size  $\sin \alpha$  <sup>increases</sup> ~~decreases~~, linearly with the overall magnification.

(3) General lay-out and function of the proposed system

A block diagram of the arrangement proposed is shown in figure 1. The observing system comprises two identical trains of optical units, one for each film viewed, which are brought together centrally into a viewing head. To obtain an increase in light level for the images, separate lamps are proposed for the illumination of the left- and right-hand films. From each lamp identical trains of optical units are used for the illumination of each of the two films.

The overall dimensions and the approximate sizes of the individual units are indicated in figure 1, which has a scale of 1:4.

Each observing system will first be analysed. An objective and prismatic type variable anamorphic system are arranged with their axes vertical. The anamorphic system has to work in collimated light, and for this reason the objective is arranged to have the film in its focal plane. The objective forms an image of the film at infinity, and focusing of the whole system must be achieved by vertical adjustment of the objective.

The anamorphic system gives a lateral displacement of the optical axis, of varying amount up to about 1" depending on the value of the anamorphic ratio used at any particular time. The anamorph has been arranged with its axis vertical in order to facilitate different choices of azimuth for the anamorphic axes.

Between the objective and anamorph is a beam-splitter which is the injection point for the reticle image. The question of the angular size of the reticle is taken up later. The objective, beam-splitter and reticle injection system must form a rigid integral unit in order to maintain accurate positioning of the reticle relative to the scene on the film. However, this unit must have its axis

coincident, but not with very high precision, with the entering axis of the anamorph. This latter may take up a variety of positions within a circle of about 1" radius, depending on the anamorphotic ratio and its azimuth. For this reason the objective/beam-splitter/reticle injection assembly must be capable of appropriate lateral displacements in a horizontal plane, so that, under any given conditions, the axis of this assembly coincides with the entering axis of the anamorph. If, in changing the anamorphotic ratio or its azimuth, it is desirable to keep to same part of the film in the field of view, the same movements have to be communicated to the table carrying the film.

The objective requires a focal length of 2 inches. It has to be such that it gives well-corrected images with apertures and field sizes varying continuously, as the zoom operates, between  $F/1.0$  and  $\eta = 0.5$  m.m. and  $F/20.0$  and  $\eta = 10.0$  m.m. It has only been possible to glance at the design problem here, but it seems within reach.

The anamorph system, shown in figure 2, is that of the Rank Taylor Hobson British Patent No. 765,775. This particular example covers an anamorphotic range of 1.31:1.96, but we are assured by their chief designer that this particular construction would work over the required range of 1:2. In accordance with the agreement reached, no attempt has been made to design such a unit beyond noting its space and optical requirements. It may be useful to note that, given the facility of varying the azimuth that has been provided, the effective overall anamorphotic ratio could be made 1:4 merely by using the system successively at its extreme position in azimuths at right angles. Alternatively this could be used to limit the range of anamorphotic ratios with the anamorph in any one azimuth.

A detailed study of the optics for the reticle injection system has not been made. This question is dealt with later in a separate section.

Above the anamorph, the optical axis is reflected along a horizontal path, where it first enters the front matching system.

The function of this is to 'match' the image and exit pupil positions of the anamorph and objective units to the following zoom system. In particular, to avoid impractically large diameters for the anamorph, it is necessary that extra-axial pencils in the low magnification position should cross the axis at, or near, the centre of the anamorph. Also the light between the anamorph and the zoom system must be collimated, with the image in that space formed at infinity. On the other hand these would be impractical positions for the object and entrance pupil for the zoom system. The front matching system is designed to accept the image and exit pupil positions needed by the anamorph, and to produce an image and exit pupil in the positions needed by the following zoom system. The techniques used in designing such matching systems have been described in 1961 (H.H. Hopkins, 'The Gaussian Optics of Multi-lens Systems', London Conference on Optical Instruments, Chapman and Hall, 1961). The requirements of the front matching system seem to be satisfied using a 2-lens system, that is two compound components separated by a distance of 9 inches. The equivalent focal lengths of these components need to be 5 inches and 16 inches respectively. The relative apertures and field sizes at which each of these components have to work are such that they are well within the capacity of an experienced lens designer to achieve. The equivalent focal length of the front matching system is 6.4 inches. The combined magnification of the objective and front matching system is thus - 3.2, where the negative sign denotes that the image is inverted.

The zoom system works with magnification continuously variable between  $-\sqrt{20}$  and  $-1/\sqrt{20}$ . This gives an overall zoom range of 1:20, although a range of 1:21 has been used in the design study to embody a safety factor. The combined magnification of the objective, matching system and zoom varies during operation of the zoom from + 0.69 to + 14.7. The design of the zoom system has constituted the kernel of the feasibility study, and this has been carried to the point of showing that the desired zoom ratio can be

achieved in a continuous range with good image quality. The zoom has been designed to work with a fixed exit pupil position, a requirement following from the need to have a fixed exit-pupil, or eye-point, for the observer. In consequence the entrance pupil for the zoom varies in position, and as a result so do the pupil positions for the preceding optical units, including the illuminating system. This leads to some problems, but ones which it seems practicable to solve at the detailed design stage. On the other hand it may be possible to apply some of the recent results emerging from the basic research programme at W. Watson & Sons on zoom systems, and thereby ease the problems arising from the wandering of the entrance pupil positions during zooming. However, in the context of the present feasibility study, it has had to be considered sufficient to establish that the problem is solvable rather than to seek really optimum solutions for each item, which would clearly demand far more time and effort than would be appropriate at this stage.

The zoom system adopted is that of the Hopkins-Watson British Patent No. 760,588. The mechanical movements are of a simple kind, and very large zoom ratios are possible. Details of this aspect of the design study are given in a later section.

Following the zoom system is a rear matching system, whose function is to pick up the image and exit pupil of the zoom and relay them to positions suitable for the viewing head. The rear matching system was designed using the same techniques as for the front matching system, and again only the equivalent focal lengths and the separation of the two elements have been determined. These are focal lengths of 7 inches and 5 inches respectively, separated by a distance 10 inches. Again the relative apertures and fields of each of the two components are such that their detailed design would be of a routine nature.

The rear-matching system produces a real image of the exit pupil of the zoom system at a short distance from the last surface of the

matching system. A fixed aperture stop will be placed in this position. The diameter of this stop requires to be 20 m.m.

Another requirement imposed on this matching system was to produce a real image of the object also 20 m.m. in diameter at a distance of 400 m.m. from the exit pupil. Thus, between the aperture stop and this image, all the image-forming pencils lie exactly within a cylinder of 20 m.m. diameter and extending for a distance of 400 m.m. along the optical axis. This condition was imposed to facilitate the design of the image rotating prism and the viewing head.

The product of the magnifications produced by the objective and front matching system, the zoom system and the rear matching system (this latter having a magnification of - 1.4) varies from  $x (-0.97)$  to  $x (-20.6)$  as the zoom is operated. The use of x10 eyepieces will thus easily give the desired range of x10 to x200.

Beyond the aperture stop is a conventional K-type of image rotating prism, which is capable of giving image rotations of  $360^{\circ}$ . The size of this prism is indicated in figure 1. The K-prism gives three reflections of the light traversing it, which together with the reflection between the anamorph and front matching system means that the image produced after the image rotating prism will be rotated to any desired orientation, but it will not be a mirror image, having experienced an even number of reflections. To avoid mirror images, therefore, the viewing head must have an even number of reflections.

The viewing head is shown in diagrammatic plan section in its different forms in figures 3a, 3b and 3c. Light entering from the left and right is reflected in a horizontal plane, passes through the switching unit in operation in any particular case, and the two emerging optical axes are then parallel in a horizontal plane and are a distance 60 m.m. apart. These axes are reflected upwards in a plane at  $45^{\circ}$  to the horizontal by means of a single inclining prism, shown in sideways section in figure 3d. To obtain interpupillary

distances between 50 m.m. and 75 m.m., each light beam passes through a rhomboid prism, the two prisms being capable of coupled rotations about the entering optical axes. A x10 eyepiece is placed at the exit face of each rhomboid prism. The output units of the viewing head, comprising inclining prism, rhomboid prisms and eyepieces are all shown in figure 3d. These items would all need to be designed in fuller detail at the final design stage, but they would appear to present no problem.

In figures 3a, 3b and 3c, the light entering the viewing head from either side first passes through a beam-splitter, the reflected beam supplying the output to the electronic scanner. It should be noted that this image is a mirror image of the object. These scanner beam-splitters remain permanently in position.

There are three different systems which may be brought into operation for the observer. These are shown in the areas within the broken lines of figures 3a, 3b and 3c. Mounted one above the other image-switching can be achieved by a vertical movement of an assembly carrying all three systems to bring the desired one into the optical train. By using pentagonal prisms in the direct stereoscopic system, shown in figure 3a, there are two reflections for each beam, avoiding the production of mirror images. Also the extra path length inside each pentagonal prism makes it possible to parfocal the other viewing systems with that of figure 3a. In consequence the image will remain in focus when the viewing head is switched from any one form of viewing to any other. Figure 3b shows the system used for reversed stereoscopic viewing, when the left-hand film has its image brought to the right eye of the observer and vice versa.

The final form, shown in figure 3c, permits ordinary binocular viewing of the left-hand film. This sub-assembly can be rotated through  $180^{\circ}$  about the centre line to view the right-hand film in the same manner. Alternatively a duplicate of the system of figure 3c could be used, but arranged to receive the light from the right-

hand film. In the system of figure 3c a long path in glass has been used in order to give an air-equivalent path of the same length as in the systems of figures 3a and 3b.

Each film has its own illuminating system and lamp, as shown in the general lay-out of figure 1. Each illuminating system comprises a zoom system followed by a condensor. The zoom system would be identical with that of the observing system, so that for any zoom position the correct area of the film is illuminated with the correct aperture for the illuminating cones. The condensor would need to have a magnification equal to the reciprocal of the combined magnification of the objective and front matching system. This, it is felt, could be achieved using a modified form of the objective system.

(4) The reticle and reticle injection system

The point of injection of the reticle is shown in figure 1 immediately above the objective. In section 3 it has been stressed that the objective, beam-splitter and reticle system must form a rigid system to preserve exact location of the reticle image relative to that of the film.

The Specification calls for the reticle image to be a luminous dot with sharply defined edges, and of size variable over a range such that its diameter subtends any angle between 0.5 and 4.0 minutes of arc at the observer's eye. The following considerations are important in relation to this part of the Specification.

The light forming the image of the reticle will of necessity pass through the anamorphic and zoom systems, and will therefore have its image-forming pencils limited in the same way, namely by the 20 m.m. diameter aperture stop placed just following the rear matching system. Thus, no matter what zoom magnification is used, the image of an ideal point source on the reticle will be imaged as an Airy disc at 250 m.m. from the eye of the observer and of diameter determined by the instrumental exit pupil. This is of

radius 0.625 m.m., corresponding to an angular diameter of the Airy disc (as subtended at the observer's eye) equal to

$$\beta' = \frac{0.61 \lambda}{0.625} \quad (15)$$

where  $\lambda$  is the wavelength of the light expressed in m.m.s. With  $\lambda = 0.0005$  m.m., this gives  $\beta' \approx 1.67$  minutes of arc. The diameter of the Airy disc will thus have an angular size of 3.34 minutes of arc.

It thus follows from (15) that even an ideal point source of light will give as image a disc of light of angular diameter 3.34 minutes of arc, that is of an angular size almost equal to the upper limit called for in the Specification. An angular size smaller than this is physically not attainable because of the diffraction-limited nature of optical systems. The upper limit of 4 minutes of arc for the reticle image would demand a size of aperture for the reticle well below the resolution limit of the system, and whose image would therefore be of essentially constant size, independent of the system forming the image and determined only by the radius of aperture of the exit pupil.

Based on the above analysis it is suggested that the reticle injection system comprise a pin-hole placed at the focus of an infinity-corrected objective of aperture not less than F/1.0. To make the actual pin-hole of more practicable size a x40 reduction of the pinhole could be used, produced using a 4 m.m. microscope objective. From what has been said above no zoom system would be needed for the reticle injection system.

(5). Design Study of the 20:1 Zoom System

As mentioned above the basic system employed is that of British Patent No. 760,588. This envisages the use of two positive components which are moved as a pair during zoom operation, their separation remaining constant. A negative component is located

between the two outer positive elements and moves differentially with respect to them. In the mean position of the zoom each component is arranged to have a magnification equal to  $-1$ , the negative sign denoting that the image is inverted relative to the object. The overall magnification in the mean position, being the product of the separate magnifications of the three components is also equal to  $-1$ .

The system is shown in figure 4, the middle diagram giving the mean position of the zoom. The remaining diagrams show progressively the positions of the three components of the zoom at equally spaced magnifications between the upper and lower limits. In the example shown these magnifications are  $-\sqrt{21}$  and  $-1/\sqrt{21}$  respectively. Even for this large zoom ratio, of 21:1, the movements of the elements are relatively small; and this is one of the advantages of the system in question. To operate the zoom a direct drive may be imparted to a mount carrying the two outer lenses, which remain a fixed distance apart, while a coupled cam is made to position the middle element. The positional accuracy needed varies over the zoom run, but would not exceed 0.001" in the system shown.

The gaussian optics of the system are determined as follows. Let  $F_1, F_2, F_3 = F$ , be the equivalent focal lengths of the three components. Then, in the mean position, the throw from object to image is given by

$$T = 2(F_1 + F_2) \quad (16)$$

$F_1$  is chosen to be positive, and  $F_2$  negative. The desired dimensions decide the value of  $T$ , so that only the ratio  $F_1/F_2$  remains as a free design parameter. For any chosen value of  $F_1/F_2$ , the separate values of  $F_1$  and  $F_2$  are given from (16).

The extreme magnifications given when the middle component is almost in contact with either of the outer components are then easily found. A value of  $F_1/F_2$  permitting the necessary ratio of extreme magnifications is selected, and the lens movements needed to vary the magnification subject to  $T$  retaining the

value (16) are easily found. At this stage the fixed exit pupil position giving the smallest lens diameters relative to focal length is determined, and adopted for the study of aberration correction.

It is necessary to ensure ab initio the possibility of achieving stable correction of all aberrations throughout the whole zoom run. For this purpose the system is studied in a thin lens approximation, each component being specified by its power  $K$ , that is the reciprocal of the equivalent focal length, and by the coefficients of spherical aberration,  $S_I$ , and central coma  $S_{II}$ , (See Hopkins, 'Wave Theory of Aberrations', Oxford University Press, 1950). These aberration coefficients are the values for each component when the zoom is in the position giving the maximum magnification. When the three components are moved to positions giving a different magnification there is a change in object position, aperture of the axial pencil and stop position for each element. The Seidel aberration coefficients for these new conditions may be written in terms of those for the high magnification position, and in this way algebraic expressions for the total spherical aberration, coma, astigmatism and distortion are obtained. This is done for a total of five zoom positions, in the present case for those shown in figure 4, thus giving five algebraic values of each of the four aberrations for the whole zoom system. These expressions contain only six variables, namely the two aberration coefficients for each of the three components when in the high magnification position.

At this stage the problem is to determine values of these six coefficients which minimise the variation in the aberrations as the zoom operates. A technique has been developed in which the variance of each aberration, that is the mean square value relative to the mean, is minimised. A further condition is added, namely that the six basic aberration coefficients,  $S_I$  and  $S_{II}$ , shall not be large. A satisfactory solution of this system of equations was arrived at, giving stable correction of the Seidel aberrations in the five zoom positions.

It then seemed that the first component could be designed using two cemented doublets, and that single cemented doublet components would suffice for the other two. These were designed to have the values of  $S_I$  and  $S_{II}$  indicated by the minimised variance solution. The resulting system was then subjected to a number of cycles of the Watson automatic correction procedure, which resulted in the system whose data is given in <sup>Figure 4.</sup> ~~section 6~~. The aberrations of this system are indicated in tables I and II. These aberrations are wave-aberrations in wavelengths, corresponding to the fringes to be seen with a lens-testing interferometer. Each of the five zoom positions is denoted by giving the numerical value of the corresponding magnification. The coordinates  $(x, y)$  give the position of the corresponding ray in the pupil, this latter being the circle  $x^2 + y^2 = 1$ . The quantity  $\mathcal{C}$  denotes the field position:  $\mathcal{C} = 0$  is the axial image, and  $\mathcal{C} = 1$  is the edge of the field. In the lower part of each table are given the chromatic aberrations along zonal rays. Table III shows the distortion at the edge of the field, shown as a percentage.

The results shown in these three tables confirm the possibility of achieving a good standard of correction of aberration over the whole zoom range. It should, nevertheless, be emphasised that the design work has only been carried to an early stage, and a great amount of design and computation would be needed to complete it.

#### (6) Summary of data

For ease of reference the constructions and functions of the different units are summarised in Table IV. The positions of the object and image relative to the first and last surfaces for each unit are denoted by  $\bar{l}$  and  $\bar{l}'$  respectively. Where appropriate the positions of the entrance and exit pupils are given, <sup>denoted</sup> ~~denoted~~ by  $\bar{l}$  and  $\bar{l}'$  respectively. The units are listed in order from the lamp through to the eyepiece.

An important factor in the expected performance is the number of surfaces traversed by the light. These are listed in Table V,

where the number of surfaces has sometimes been estimated, for example for the eyepieces.

From Table V it will be seen that very efficient anti-reflection coatings and high reflectivity reflecting surfaces would be essential in the interests of both light transmission and reduction of stray light. For example, 2-layer blooming should be used on all low-index glass surfaces. The condensor has one reflection and 22 transmissions at air glass surfaces. If a reflectivity of 95% and transmission of coated surfaces of 98% are assumed, the estimated transmission of the condensor system will be

$$100 (0.95) (0.98)^{22} = 61\%$$

The corresponding figures for the viewing system are 12 and 46 giving an estimated transmission of

$$100 (0.95)^{12} (0.98)^{46} = 21\%$$

These together give an expected total transmission of

$$100 (.61 \times .21) = 13\%$$

In addition to the above light losses, it has to be noted that there will be two beam splitters, which will reduce the light transmission to about 25% of the above value.

#### (7) Conclusion

The investigation has shown that the basic requirements of the Specification, although very exacting, could be met as regards magnification, zooming, and image-switching. Moreover a high degree of correction of aberration should also be possible, despite the formidable design problem that it still presents. From the study made it seems inevitable that the system would have a large number of elements and surfaces, which would have to be made to the very highest optical standards. Even then it is doubtful whether the design goals in relation to resolution would be met fully.

However, as shown earlier, these seem excessive in relation to the visual acuity of the normal observer. Detail corresponding to 500 lines/m.m. at x200 and 25 lines/m.m. at x10 might be expected to be seen by good observers. These would correspond to a reduced spatial frequency of  $s = 0.5$ , which still calls for the highest quality in the optics. (See, for example, Hopkins 'The aberration permissible in optical systems', Proc. Phys. Soc. B, Vol. LXX, p. 449, 1957). Such a system should be achievable, but only at very high cost.

HHH/JM

TABLE I

Wave-aberrations, in wavelengths, at different magnifications:  $\overline{C} = 0$

	x	y	Magnification				
			0.227	0.456	1.045	2.367	4.636
Monochromatic aberrations	0	1	-1.9	+0.3	+0.3	+0.1	+0.1
	0	$\sqrt{\frac{2}{3}}$	-0.1	+0.1	+0.1	+0.1	+0.0
	0	$\sqrt{\frac{1}{3}}$	+0.1	+0.0	+0.0	+0.1	+0.0
Chromatic aberration	0	$\sqrt{\frac{1}{2}}$	+1.6	+1.2	+0.6	+0.3	+0.2

TABLE II

Wave-aberrations, in wavelengths, at different magnifications:  $\overline{C} = 1$

	x	y	Magnification				
			0.227	0.456	1.045	2.367	4.636
Monochromatic aberrations	0	1	-1.5	+1.8	+1.1	+1.5	+1.9
	0	$\sqrt{\frac{2}{3}}$	+0.6	+1.5	+0.9	+1.0	+1.2
	0	$\sqrt{\frac{1}{3}}$	+0.6	+0.8	+0.5	+0.5	+0.6
	0	$-\sqrt{\frac{1}{3}}$	+0.9	+1.0	+1.0	+0.7	+0.6
	0	$-\sqrt{\frac{2}{3}}$	+2.5	+2.1	+2.1	+1.4	+1.2
	0	-1	+4.5	+3.2	+3.4	+2.2	+1.8
	1	0	-1.1	+1.1	+1.0	+0.7	+0.5
Chromatic aberration	0	$\sqrt{\frac{1}{2}}$	+0.8	+0.6	+0.3	+0.2	+1.2
	0	$-\sqrt{\frac{1}{2}}$	+3.2	+0.5	+0.2	+0.4	-0.4

TABLE III

Percentage distortion at different magnifications:  $\overline{C} = 1$

Magnification				
0.227	0.456	1.045	2.367	4.636
+ 0.1	-0.1	-0.4	-0.9	-0.1

TABLE IV

Unit	Construction	Focal length or magnification	$l$	$l'$	$\bar{l}$	$\bar{l}'$
Lamp Matching system	2 separated doublets	Not determined in detail				
Condensor zoom	As for viewing zoom					
Condensor	As for objective + front matching system					
Objective	Not known in detail	$F = 2$	-	$\infty$	vary with zooming	
Anamorph	2 separated compound prisms	2:1 variable	$\infty$	$\infty$	vary with zooming	
Front Matching system	2 separated doublets $F_1 = +5$ $F_2 = +16$ $d_{1,2} = 9$	$F = -6.5$	$\infty$	-5.8	vary with zooming	
Zoom	3 components (for details see fig. 4)	$M = -\sqrt{21}:$ $-\frac{1}{\sqrt{21}}$	vary with zooming			
Rear Matching system	2 separated doublets $F_1 = +7$ $F_2 = +5$ $d_{1,2} = 10$	$M = -1.4$	+5.9	+18.0	-14.2	+2.0
Image Rotator	K-prism	Not	relevant			
Viewing Head	Image-switching units, inclining prism, rhomboid prism	Not	relevant			
Eyepieces	Not known in detail	$M = \times 10$	-	-	-	-
<u>UNIT = 1 INCH</u>						

TABLE V

Unit	No. of Surfaces	No. of air/ glass surfaces	No. of reflections
Lamp matching system	6	4	0
Condensor zoom	12	8	0
Reflecting prism	3	2	1
Condensor	10	8	0
Objective	10	8	0
Beam splitter	3	2	1
Anamorph	7	4	0
Reflecting prism	3	2	1
Front matching system	6	4	0
Zoom	12	8	0
Rear matching system	6	4	0
Image rotator	5	2	3
Scanner beam splitter	3	2	1
Direct stereoscopic prism system	2	2	2
Reversed stereoscopic prism system	4	4	4
Binocular viewing prism system	7	4	4
Inclining prism	2	2	2
Rhomboid prism	4	2	2
Eyepiece	5	4	0
TOTALS for direct stereo viewing	99	68	13

## PATENT SPECIFICATION

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International Classification:—G02b.

## COMPLETE SPECIFICATION

## Improvements in or relating to Anamorphic Optical Systems

We, KENNETH ROY COLEMAN, British Subject, and TAYLOR, TAYLOR & HONSON LIMITED, a Company registered under the Laws of Great Britain, both of 104, Stoughton Street, Leicester, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to an anamorphic optical system, comprising two refracting compound prisms so arranged that an incident ray will be deviated in one sense by the first compound prism and in the reverse sense by the second compound prism. The total deviation of an incident ray by such a system will depend on its angle of incidence on the first surface, and the term "axial ray" is herein used to denote a ray which emerges from the system parallel to its direction of incidence. It is to be noted that an incident collimated beam composed of axial rays will not only be deviated by the compound prism on which it is incident, but will also be reduced (or enlarged) in cross-section, and this action will be repeated at the other compound prism, the reduction (or enlargement) of course taking place only in a plane at right angles to the generators of the prisms, the dimensions of the beam at right angles to such plane remaining unaltered. This change in width of an axial collimated beam may conveniently be termed "lateral pupil compression (or enlargement)". At the same time, the angle between two oblique incident rays will be decreased (or increased) in their passage through the system, in the operative plane at right angles to the prism generators, but will remain unaltered in a plane at right angles thereto. Such change in angle may be termed "lateral angular compression (or enlargement)", and it is particularly to be noted that lateral pupil compression and lateral angular compression are operative in opposite senses, so that a beam passing through the system in one direction will suffer lateral pupil enlargement, whilst a beam passing

through the system in the opposite direction will suffer lateral angular enlargement and lateral pupil compression. It will thus be clear that the system has an overall magnification factor in the operative plane equal to the reduction in width of pupil, but leaves the dimensions and direction of a beam unaltered in the plane at right angles thereto.

The anamorphic system is primarily intended for use in front of a main objective, that is on the long conjugate side of the objective, and it is to be understood that the terms "front" and "rear," as applied herein to the anamorphic system, are to be interpreted in the same sense as for the main objective with which it is to be used, so that the rear of the anamorphic system is the side thereof adjacent to the main objective whilst the front of such system is the side remote from the objective.

The present applicants' copending British Patent Application No. 29675 of 1953 (Serial No. 745,315) relates to a system of this kind, having each of the two compound prisms in the form of a doublet, in which the two prism elements have their apices pointing in opposite directions, the apices of the two inner prism elements of the system pointing in the same direction, wherein an axial ray incident on the system from the front is deviated by the front doublet in a sense away from the apices of the inner prism elements and by the rear doublet in a sense towards such apices, the portion of such axial ray within each prism element being inclined to the normal to the cemented surface at an angle which exceeds by at least five degrees the angle between such ray portion and the normal to the air-exposed surface of the prism element, the Abbé V number of the front prism element of each doublet exceeding that of the associated rear prism element by at least 10. This arrangement is such as to enable the two compound prisms to be angularly adjusted about axes parallel to the generator of the prism surfaces to vary the magnification of the system and to maintain

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correction for axial colour over a wide range of magnification. This is achieved, however, by the use of small prism angles and large air angles, which makes the complete system unduly long.

The present applicants' copending British Patent Applications Nos. 29797 and 30948 of 1953 (Serial No. 746,194) also relate to systems of this kind, wherein each compound prism is arranged to depart from achromatism to such an extent that the difference between the deviations of an axial ray through the compound prism for the C and F spectrum lines lies between .01 and .1 of a degree. In this way, in addition to correction for axial colour, a limited degree of correction for oblique colour can also be maintained over an appropriate range of magnifications or alternatively a high degree of correction for oblique colour over a narrow magnification range.

The present invention has for its primary object to provide an improved system whereby a high degree of correction for axial colour can be satisfactorily maintained over a wide magnification range, without undue length in the system. A further object is still further to improve the system to maintain good correction for oblique colour, in addition to axial colour, over a wide magnification range.

The anamorphic system, according to the present invention, comprises two refracting compound prisms so arranged that an incident ray will be deviated in one sense by the first compound prism and in the reverse sense by the second compound prism to an extent sufficient to include an axial ray within the useful field, the front compound system being in the form of a triplet, the middle element of which is made of material having Abbé V number of less than 45, whilst each of the outer elements has its apex pointing in a direction opposite to that of the middle element and is made of material whose Abbé V number is greater than 45 and exceeds that of the middle element by at least 10, the prism angle of the front element lying between 0.1 and 1.5 times the prism angle of the rear element. The prism angle of such rear element preferably lies between 10° and 40°, whilst that of the middle element lies between 9° and 25° and is less than the sum of the prism angles of the front and rear elements by more than 10°.

The rear compound prism can be arranged in various ways.

Thus, the rear compound prism may be in the form of a doublet with the apices of its two elements pointing in opposite directions, the front element being made of material having Abbé V number less than 45 whilst the rear element is made of material having Abbé V number greater than 45 and exceeding that of the front element by at least 10, such rear element having a prism angle at

least 6° greater than the prism angle of the front element. In such case, the prism angle of the front element of the front compound prism preferably lies between 0.1 and 0.67 times the prism angle of the rear element of such compound prism.

Alternatively, the rear compound prism may be in the form of a triplet, whose middle element has its apex pointing in a direction opposite to those of the outer elements, the material of the middle element having Abbé V number less than 45, whilst those of the outer elements each have Abbé V number greater than 45 and exceeding that of the middle element by at least 10, the sum of the prism angles of the outer elements exceeding the prism angle of the middle element by at least six degrees. In such case, the prism angle of the front element of the front compound prism preferably lies between .67 and 1.5 times that of the rear element of such compound prism.

In these arrangements, it is advantageous to employ the same materials for the elements of one compound prism as for those of the other compound prism.

Variation of the magnification of the system may be effected by angularly adjusting the two compound prisms about axes parallel to the prism surfaces. In such case, it is desirable to choose the relative angular movements so that an incident ray, which in one position of adjustment emerges parallel to its original direction of incidence, will also emerge parallel to its original direction in all other positions of adjustment. The two compound prisms may be so arranged that in one position in the range of adjustment each compound prism is approximately achromatic.

The invention may be carried into practice in various ways, but some convenient alternative example of anamorphic optical system according to the invention are diagrammatically illustrated by way of example in the accompanying drawings, in which

Figure 1 illustrates an example having a triplet front compound prism and a doublet rear compound prism shown in its position of maximum magnification,

Figure 2 shows the example of Figure 1 in its position of minimum magnification,

Figure 3 illustrates another example having a triplet front compound prism and a doublet rear compound prism,

Figures 4-6 respectively illustrate three further examples each having both compound prisms in the form of triplets,

Figures 7 and 8 are views respectively parallel to and at right angles to the prism generators showing the example of Figure 1 applied by way of example to an optical projection arrangement,

Figure 9 illustrates one form of mechanism for adjusting the magnification of the anamorphic system as applied to the example of

Figure 1, Figure 10 illustrates an alternative form of adjusting mechanism as applied to the example of Figure 6, and

Figures 11 and 12 are views at right angles to one another showing the use of two similar anamorphic systems according to the invention having their prism generators at right angles to one another for increasing the effective angular field of the objective with which they are used.

Numerical data for the examples of Figure 1 and Figures 2-6 are given respectively in the following five tables. In each of these tables, the first portion gives for each of the prism elements, counting from the front, the apex angle  $\theta$  in degrees, the refractive indices  $N_D$ ,  $N_C$  and  $N_F$  respectively for the C, d and F spectrum lines of the material of which the element is made, and also the Abbé V number for such material. The second portion of each table is concerned with angular adjustment of the two compound prisms to vary the magnification of the system, and gives data for various positions of adjustment for an axial ray passing through the system from the rear to the front, such data comprising the angle of incidence  $i$  in degrees of the ray to the normal to the rear surface of the rear compound prism (the positive sign indicating that the ray is on the side of the normal remote from the "closed" side of the system, that is the side of the system towards which the apex of the prismatic air space between the two compound prisms points in the position of highest magnification, whilst the negative sign indicates that the ray is on the side of the normal nearer to such closed side), the angle  $\phi$  in degrees between the rear surface of the front compound prism and the front surface of the rear compound prism (the positive sign indicating that such angle points towards the closed side and the negative sign that it points away therefrom), and the overall magnification M of the system.

EXAMPLE I

	$\theta$	NC	Nd	NF	V
Prism 1	8.0	1.51385	1.51633	1.52191	64.1
Prism 2	14.48	1.61546	1.62049	1.63258	36.2
Prism 3	29.0	1.51385	1.51633	1.52191	64.1
Prism 4	12.27	1.61546	1.62049	1.63258	36.2
Prism 5	33.25	1.51385	1.51633	1.52191	64.1

$i$	$\phi$	M
+22.14	+75.25	1.96
+19.93	+69.39	1.76
+16.10	+60.07	1.54
+10.00	+44.71	1.31

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EXAMPLE II

	$\theta$	NC	Nd	NF	V
Prism 1	7.0	1.50727	1.50970	1.51518	64.4
Prism 2	14.15	1.61546	1.62049	1.63258	36.2
Prism 2	30.0	1.50727	1.50970	1.51518	64.4
Prism 4	12.08	1.61546	1.62049	1.63258	36.2
Prism 5	33.25	1.50727	1.50970	1.51518	64.4

$i$	$\theta$	M
+22.2	+75.3	1.96
+19.8	+68.9	1.74
+15.8	+59.1	1.52
+ 9.0	+41.9	1.28
- 3.0	+12.5	1.06
-48.0	-58.9	.64

EXAMPLE III

	$\theta$	NC	Nd	NF	V
Prism 1	20.0	1.50727	1.50970	1.51518	64.4
Prism 2	20.78	1.61546	1.62049	1.63258	36.2
Prism 3	23.0	1.50727	1.50970	1.51518	64.4
Prism 4	17.55	1.50727	1.50970	1.51518	64.4
Prism 5	17.04	1.61546	1.62049	1.63258	36.2
Prism 6	17.55	1.50727	1.50970	1.51518	64.4

$i$	$\theta$	M
+28.6	+77.7	1.97
+22.1	+59.1	1.49
+16.0	+39.0	1.25
- 5.0	+ 5.5	1.03
-52.5	-65.97	.65

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EXAMPLE IV

	$\theta$	NC	Nd	NF	V
Prism 1	17.0	1.50727	1.50970	1.51518	64.4
Prism 2	17.81	1.61546	1.62049	1.63258	36.2
Prism 3	20.0	1.50727	1.50970	1.51518	64.4
Prism 4	17.55	1.50727	1.50970	1.51518	64.4
Prism 5	16.93	1.61546	1.62049	1.63258	36.2
Prism 6	17.55	1.50727	1.50970	1.51518	64.4

$i$	$\theta$	M
+27.3	+83.0	1.99
+21.0	+67.8	1.56
+13.8	+50.7	1.31
- 3.0	+ 9.5	1.04
+49.4	-67.4	.65

EXAMPLE V

	$\theta$	NC	Nd	NF	V
Prism 1	17.0	1.50727	1.50970	1.51518	64.4
Prism 2	17.78	1.61546	1.62049	1.63258	36.2
Prism 3	20.0	1.50727	1.50970	1.51518	64.4
Prism 4	14.6	1.50727	1.50970	1.51518	64.4
Prism 5	14.13	1.61546	1.62049	1.63258	35.2
Prism 6	14.6	1.50727	1.50970	1.51518	64.4

$i$	$\theta$	M
+34.0	+83.7	1.96
+27.3	+64.4	1.47
+22.5	+49.5	1.29
- 3.0	+4.0	1.02
-55.6	-76.0	.64

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In Figures 1 and 2, a few typical rays are shown, including a central axial ray incident at angle  $i$  to the normal to the rear surface of the rear compound prism and emerging from the front surface of the front compound prism in a direction substantially parallel to its original direction of incidence, and two further axial rays equally spaced on either side of the central axial ray. It will be noticed that these axial rays emerge from the front of the system much closer together than they were at incidence, thus illustrating the lateral pupil compression of rays passing from rear to front. Two oblique rays are also shown one on either side of the central axial ray and equally inclined thereto at incidence. These oblique rays emerge from the front of the system at greater inclination to the axial rays, thus illustrating lateral angular enlargement of rays passing from rear to front. It will be at once clear that rays passing from front to rear would have lateral pupil enlargement and lateral angular compression. The magnification of the system is proportional to the lateral pupil compression, and the reduced magnification of the system with the prisms adjusted to the positions shown in Figure 2 will be clear from the greater width of the emergent axial beam in Figure 2 as contrasted with that in Figure 1.

In the first two examples (Figures 1 and 3), the rear compound prism is in the form of a doublet, with the apex of the front element pointing towards the closed side and that of the rear element pointing away therefrom. In the remaining three examples, Figures 4-6, the rear compound prism is in the form of a triplet, with the apex of the middle element pointing towards the closed side and the apices of the other two elements pointing away therefrom. The material of lower element of the triplet front compound prism, in all five examples, points away from the closed side, whilst the apices of the front and rear elements thereof point towards the closed side.

In each of the five examples, the same two materials are used in the front compound prism as in the rear compound prism, the difference between the two Abbé V numbers being 27.9 in Example I and 28.2 in the remaining examples. The material of lower element of the triplet front compound prism, in all five examples, points away from the closed side, whilst the apices of the front and rear elements thereof point towards the closed side.

In each of the five examples, the same two materials are used in the front compound prism as in the rear compound prism, the difference between the two Abbé V numbers being 27.9 in Example I and 28.2 in the remaining examples. The material of lower element of the triplet front compound prism, in all five examples, points away from the closed side, whilst the apices of the front and rear elements thereof point towards the closed side.

The ratio of the prism angle of the front element of the rear doublet in Examples I and II, and for the middle element of the rear triplet in Examples III, IV and V.

The ratio of the prism angle of the front element of the rear triplet to that of the rear element of such triplet is 0.28 in Example I, 0.23 in Example II, 0.87 in Examples III and 0.85 in Examples IV and V. The sum of such two prism angles exceeds the prism angle of the middle element of the front triplet by 22.52 in Example I, 22.85 in Example II, 22.22

in Example III, 19.19 in Example IV and 19.22 in Example V, in each case in Degrees.

In the first two examples, the prism angle of the rear element of the rear doublet exceeds that of the front element thereof by 20.98 degrees in Example I and by 21.17 degrees in Example II. In the remaining three examples, the sum of the prism angles of the outer element of the middle element of such triplet by 18.06 degrees in Example III, by 18.17 degrees in Example IV and by 15.07 degrees in Example V.

The second portion of the various tables give data for the useful ranges of magnification of the examples, and steps are provided to limit the adjustment to such range, since the aberration corrections are not maintained outside the range. In each case, the relationships are such that an incident ray which is an axial ray in any one position of adjustment remains an axial ray throughout the range of adjustment. Example I, with a somewhat smaller range of adjustment than the other examples, has the property that the angular movements of the two compound prisms bear an approximately linear relationship to one another. The arrangements are also such that, in each case, in the position of highest magnification, the two compound prisms are each approximately achromatic.

The rotational adjustment of the two compound prisms about axes parallel to the prism generators, to vary the magnification, may be effected separately by hand control, for example by means of hand knobs, as indicated at A in Figure 8, or the two prisms may be mechanically interlinked in various ways to correlate their movements. With the approximately linear relationship between the movements of the two compound prisms in the first example, it is practicable for the two prisms to be directly geared together at the appropriate ratio, as shown by the two gear wheels B B' in Figure 9, one of the gear wheels carrying a projection C movable between two fixed stops C' C'' to limit the adjusting movement.

Figure 10 illustrates an alternative form of mechanism, which can be used also when the relationship between the two movements is not linear. This mechanism comprises a disc D carried by one compound prism and having a cam slot D', within which runs a pin E on an arm E' carried by the other prism, the shape of the cam slot D' being chosen to suit the relationship between the two movements. The ends of the slot D' act as stops to limit the movement.

In the first two examples, employing a rear doublet, good correction for axial colour is maintained throughout the range of magnification, whilst in the other three examples, employing a rear triplet, not only good axial colour correction, but also good oblique colour

correction is maintained throughout the magnification range.

The anamorphic system according to the invention is primarily intended for use in front of a main objective, in a collimated beam of light. In cases where the light is not already collimated, a collimating lens system is provided in front of the anamorphic system. Such an arrangement is illustrated in Figures 7 and 8, the main objective being indicated diagrammatically at F and the collimating lens system at G, such system having focal length equal to the distance from the plane H, which constitutes either the image plane or the object plane in accordance with the direction

in which the rays pass through the system, the focal plane of the objective F (which is focussed on infinity) being indicated at J. If the system is used for the projection on to a screen of a laterally compressed image or a cinematograph film, the film is located at the short conjugate plane J on the rear side of the main objective F and the system will act to broaden out the laterally compressed film image to give a screen image at H in its normal undistorted proportions. If on the other hand, the system is used for photographing a broad panoramic scene on to a cinematograph film, the scene to be photographed will lie in the neighbourhood of the long conjugate plane H in front of the system and the film in the short conjugate plane J, and the system will act to produce on the film a laterally compressed image of the scene, suitable for subsequent projection in the manner just described to produce a screen image in the original proportions of the panoramic scene.

The anamorphic system according to the invention is also suitable for use in the manner forming the subject of the present applicants' copending British Patent Application No. 10749 of 1954 (Serial No. 747,228) in conjunction with a second similar anamorphic system whose prism generators lie at right angles to those of the first system, in cooperation with a main objective and a collimating lens system, to increase the effective angular field of the objective for wide angle work. In such case, the prisms may be fixed in position, or alternatively, the two systems may be adjustable to give variable magnifications in the two operative planes.

Such a double anamorphic system is shown in two views at right angles respectively in Figures 11 and 12, the front system K K' being appropriately larger than the rear system L L'. The main objective and collimating lens system are omitted from Figures 11 and 12, but are of course arranged respectively behind and in front of the double anamorphic system in a manner analogous to that shown in Figures 7 and 8.

What we claim is:—

1. An anamorphic optical system, comprising two refracting compound prisms so

arranged that an incident ray will be deviated in one sense by the first compound prism and in the reverse sense by the second compound prism to an extent sufficient to include an axial ray within the useful field, the front compound prism being in the form of a triplet, the middle element of which is made of material having Abbé V number less than 45 whilst each of the outer elements has its apex pointing in a direction opposite to that of the middle element and is made of material whose Abbé V number is greater than 45 and exceeds that of the middle element by at least 10, the prism angle of the front element lying between 0.1 and 1.5 times the prism angle of the rear element.

2. An anamorphic optical system as claimed in Claim 1, in which the prism angle of the rear element of the front compound prism lies between 10° and 40°, whilst that of the middle element lies between 9° and 25° and is less than the sum of the prism angles of the front and rear elements by more than 10°.

3. An anamorphic optical system as claimed in Claim 1 or Claim 2, in which the rear compound prism is in the form of a doublet with the apices of its two elements pointing in opposite directions, the front element being made of material having Abbé V number less than 45, whilst the rear element is made of material whose Abbé V number is greater than 45 and exceeds that of the front element by at least 10, such rear element having a prism angle at least 6° greater than the prism angle of the front element.

4. An anamorphic optical system as claimed in Claim 3, in which the prism angle of the front element of the front compound prism lies between 0.1 and 0.67 times the prism angle of the rear element of such compound prism.

5. An anamorphic optical system as claimed in Claim 1 or Claim 2, in which the rear compound prism is in the form of a triplet whose middle element has its apex pointing in a direction opposite to those of the outer elements, the material of the middle element having Abbé V number less than 45, whilst those of the outer elements each have Abbé V number greater than 45 and exceeding that of the middle element by at least 10, the sum of the prism angles of the outer elements exceeding the prism angle of the middle element by at least 6°.

6. An anamorphic optical system as claimed in Claim 5, in which the prism angle of the front element of the front compound prism lies between .67 and 1.5 times that of the rear element of such compound prism.

7. An anamorphic optical system as claimed in any one of Claims 1-6, in which the materials used for the elements of one compound prism are the same as those used for the elements of the other compound prism.

8. An anamorphic optical system as 130

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claimed in any one of Claims 1-7, in which the two compound prisms are angularly adjustable about axes parallel to the prism surfaces to vary the magnification of the system.

9. An anamorphic optical system as claimed in Claim 8, in which the relative angular movements of the two compound prisms are such that an incident ray, which in one position of adjustment emerges substantially parallel to its original direction of incidence, will also emerge substantially

parallel to its original direction in all other positions of adjustment.

10. An anamorphic optical system as claimed in Claim 8 or 9, in which in one position in the range of adjustment each compound prism is approximately achromatic.

11. An anamorphic optical system substantially in any one of the embodiments described with reference to the accompanying drawings.

A. F. PULLINGER,  
Agent for the Applicants.

#### PROVISIONAL SPECIFICATION

#### Improvements in or relating to Anamorphic Optical Systems

We, KENNETH ROY COLEMAN, British Subject, and TAYLOR, TAYLOR & HOBSON LIMITED, a Company registered under the Laws of Great Britain, both of 104, Stoughton Street, Leicester, do hereby declare this invention to be described in the following statement:-

This invention relates to an anamorphic optical system, comprising two refracting compound prisms so arranged that an incident ray will be deviated in one sense by the first compound prism and in the reverse sense by the second compound prism. The total deviation of an incident ray by such a system will depend on its angle of incidence on the first surface, and the term "axial ray" is herein used to denote a ray which emerges from the system parallel to its direction of incidence. It is to be noted that an incident collimated beam composed of axial rays will not only be deviated by the compound prism on which it is incident, but will also be reduced (or enlarged) in cross-section, and this action will be repeated at the other compound prism, the reduction (or enlargement) of course taking place only in a plane at right angles to the generators of the prisms, the dimensions of the beam at right angles to such plane remaining unaltered. This change in width of an axial collimated beam may conveniently be termed "lateral pupil compression (or enlargement)". At the same time, the angle between two oblique incident rays will be decreased (or increased) in their passage through the system, in the operative plane at right angles to the prism generators, but will remain unaltered in a plane at right angles thereto. Such change in angle may be termed "lateral angular compression (or enlargement)", and it is particularly to be noted that lateral pupil compression and lateral angular compression are operative in opposite senses, so that a beam passing through the system in one direction will suffer lateral angular compression and lateral pupil enlargement, whilst a beam passing through the system in the opposite direction will suffer lateral angular enlargement and lateral pupil compression. It will thus be clear that

the system has an overall magnification factor in the operative plane equal to the reduction in width of pupil, but leaves the dimensions and direction of a beam unaltered in the plane at right angles thereto.

The anamorphic system is primarily intended for use in front of a main objective, that is on the long conjugate side of the objective, and it is to be understood that the terms "front" and "rear," as applied herein to the anamorphic system, are to be interpreted in the same sense as for the main objective with which it is to be used, so that the rear of the anamorphic system is the side thereof adjacent to the main objective whilst the front of such system is the side remote from the objective.

The present applicants' copending British Patent Application No. 29675 of 1955 (Serial No. 745,315) relates to a system of this kind, having each of the two compound prisms in the form of a doublet, in which the two prism elements have their apices pointing in opposite directions, the apices of the two inner prism elements of the system pointing in the same direction, wherein an axial ray incident on the system from the front is deviated by the front doublet in a sense away from the apices of the inner prism elements and by the rear doublet in a sense towards such apices, the portion of such axial ray within each prism element being inclined to the normal to the cemented surface at an angle which exceeds by at least five degrees the angle between such ray portion and the normal to the air-exposed surface of the prism element, the Abbé V number of the front prism element of each doublet exceeding that of the associated rear prism element by at least 10. This arrangement is such as to enable the two compound prisms to be angularly adjusted about axes parallel to the generators of the prism surfaces to vary the magnification of the system and to maintain correction for axial colour over a wide range of magnifications. This is achieved, however, by the use of small prism angles and large air angles, which makes the complete system unduly long.

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The present applicants' copending British Patent Applications Nos. 29797 and 30948 of 1953 (Serial No. 746,194) also relate to systems of this kind, wherein each compound prism is arranged to depart from achromatism to such an extent that the difference between the deviations of an axial ray through the compound prism for the C and F spectrum lines lies between .01 and 1 of a degree. In this way, in addition to correction for axial colour, a limited degree of correction for oblique colour can also be maintained over an appreciable range of magnifications or alternatively a high degree of correction for oblique colour over a narrow magnification range.

The present invention has for its primary object to provide an improved system whereby a high degree of correction for axial colour can be satisfactorily maintained over a wide magnification range, without undue length of the system. A further object is still further to improve the system to maintain good correction for oblique colour, in addition to axial colour, over a wide magnification range.

The anamorphic system, according to the present invention, comprises two refracting compound prisms so arranged that an incident ray will be deviated in one sense by the first compound prism and in the reverse sense by the second compound prism to an extent sufficient to include an axial ray within the useful field, the front compound system being in the form of a triplet, the middle element of which is made of material having Abbé V number less than 45, whilst each of the outer elements has its apex pointing in a direction opposite to that of the middle element and is made of material whose Abbé V number is greater than 45 and exceeds that of the middle element by at least 10, the prism angle of the front element lying between 0.1 and 1.5 times the prism angle of the rear element. The prism angle of such rear element preferably lies between 10° and 40°, whilst that of the middle element lies between 9° and 25° and is more than 10° less than the sum of the prism angles of the front and rear elements.

The rear compound prism can be arranged in various ways.

Thus, the rear compound prism can be in the form of a doublet with the apices of its two elements pointing in opposite directions, the front elements being made of material having Abbé V number less than 45, whilst the rear element is made of material having Abbé V number greater than 45 and exceeding that of the front element by at least 10, such rear element having a prism angle at least 6° greater than the prism angle of the front element. In such case, the prism angle of the front element of the front compound prism preferably lies between .01 and .67 times the prism angle of the rear element of such compound prism.

Alternatively, the rear compound prism

may be in the form of a triplet, whose middle element has its apex pointing in a direction opposite to those of the outer elements, the material of the middle element having Abbé V number less than 45, whilst those of the outer elements each have Abbé V number greater than 45 and exceeding that of the middle element by at least 10, the sum of the prism angles of the outer elements exceeding the prism angle of the middle element by at least six degrees. In such case, the prism angle of the front element of the front compound prism preferably lies between .67 and 1.5 times that of the rear element of such compound prism.

In these arrangements, it is advantageous to employ the same materials for the elements of one compound prism as for those of the other compound prism.

Variation of the magnification of the system may be effected by angularly adjusting the two compound prisms about axes parallel to the prism surfaces. In such case, it is desirable so to choose the relative angular movements that an incident ray, which in one position of adjustment emerges parallel to its original direction of incidence, will also emerge parallel to its original direction in all other positions of adjustment. The two compound prisms may be so arranged that in one position in the range of adjustment each compound prism is approximately achromatic.

The invention may be carried into practice in various ways, but the following may be instanced as some convenient alternative examples of anamorphic optical system according to the invention.

Numerical data for these examples are given in the following tables. In each of these tables, the first portion gives for each of the prism elements, counting from the front, the apex angle  $\theta$  in degrees, the refractive indices  $N_d$ ,  $N_F$  and  $N_C$  respectively for the C, d and F spectrum lines of the material of which the element is made, and also the Abbé V number for such material. The second portion of each table is concerned with angular adjustment of the two compound prisms to vary the magnification of the system, and gives data for various positions of adjustment for an axial ray passing through the system from the rear to the front, such data comprising the angle of incidence  $i$  in degrees of the ray to the normal to the rear surface of the rear compound prism (the positive sign indicating that the ray is on the site of the normal remote from the "closed" side of the system, that is the side of the system towards which the apex of the prismatic air space between the two compound prisms points in the position of highest magnification, whilst the negative sign indicates that the ray is on the side of the normal nearer to such closed side), the angle  $\phi$  in degrees between the rear surface of the front compound prism and the front surface 130

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of the rear compound prism (the positive sign away therefrom), and the overall magnification indicating that such angle points towards the M of the system.

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## EXAMPLE I

	$\theta$	NC	Nd	NF	V
Prism 1	8.0	1.51385	1.51633	1.52191	64.1
Prism 2	14.48	1.61546	1.62049	1.63258	36.2
Prism 3	29.0	1.51385	1.51633	1.52191	64.1
Prism 4	12.27	1.61546	1.62049	1.63258	36.2
Prism 5	33.25	1.51385	1.51633	1.52191	64.1

$i$	$\theta$	M
+22.14	+75.25	1.96
+19.93	+69.39	1.76
+16.10	+60.07	1.54
+10.00	+44.71	1.31

## EXAMPLE II

	$\theta$	NC	Nd	NF	V
Prism 1	7.0	1.50727	1.50970	1.51518	64.4
Prism 2	14.15	1.61546	1.62049	1.63258	36.2
Prism 2	30.0	1.50727	1.50970	1.51518	64.4
Prism 4	12.08	1.61546	1.62049	1.63258	36.2
Prism 5	33.25	1.50727	1.50970	1.51518	64.4

$i$	$\theta$	M
+22.2	+75.3	1.96
+19.8	+68.9	1.74
+15.8	+59.1	1.52
+ 9.0	+41.9	1.28
- 3.0	+12.5	1.06
-48.0	-58.9	.64

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## EXAMPLE III

	$\theta$	NC	Nd	NF	V
Prism 1	20.0	1.50727	1.50970	1.51518	64.4
Prism 2	20.78	1.61546	1.62049	1.63258	36.2
Prism 3	23.0	1.50727	1.50970	1.51518	64.4
Prism 4	17.55	1.50727	1.50970	1.51518	64.4
Prism 5	17.04	1.61546	1.62049	1.63258	36.2
Prism 6	17.55	1.50727	1.50970	1.51518	64.4

$i$	$\theta$	M
+28.6	+77.7	1.97
+22.1	+59.1	1.49
+16.0	+39.0	1.25
- 5.0	+ 5.5	1.03
-52.5	-65.97	.65

## EXAMPLE IV

	$\theta$	NC	Nd	NF	V
Prism 1	17.0	1.50727	1.50970	1.51518	64.4
Prism 2	17.81	1.61546	1.62049	1.63258	36.2
Prism 3	20.0	1.50727	1.50970	1.51518	64.4
Prism 4	17.55	1.50727	1.50970	1.51518	64.4
Prism 5	16.93	1.61546	1.62049	1.63258	36.2
Prism 6	17.55	1.50727	1.50970	1.51518	64.4

$i$	$\theta$	M
+27.3	+83.0	1.99
+21.0	+67.8	1.56
+13.8	+50.7	1.31
- 3.0	+ 9.5	1.04
+49.4	-67.4	.65

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## EXAMPLE V

	$\theta$	NC	Nd	NF	V
Prism 1	17.0	1.50727	1.50970	1.51518	64.4
Prism 2	17.78	1.61546	1.62049	1.63258	36.2
Prism 3	20.0	1.50727	1.50970	1.51518	64.4
Prism 4	14.6	1.50727	1.50970	1.51518	64.4
Prism 5	14.13	1.61546	1.62049	1.63258	35.2
Prism 6	14.6	1.50727	1.50970	1.51518	64.4

$i$	$\theta$	M
+34.0	+83.7	1.96
+27.3	+64.4	1.47
+22.5	+49.5	1.29
- 3.0	+4.0	1.02
-55.6	-76.0	.64

In the first two examples, the rear compound prism is in the form of a doublet, with the apex of the front element pointing towards the closed side and that of the rear element pointing away therefrom. In the remaining three examples, the rear compound prism is in the form of a triplet, with the apex of the middle element pointing towards the closed side and the apices of the other two elements pointing away therefrom. The apex of the middle element of the triplet front compound prism, in all five examples, points away from the closed side, whilst the apices of the front and rear elements thereof point towards the closed side.

In each of the five examples, the same two materials are used in the front compound prism as in the rear compound prism, the difference between the two Abbe V numbers being 27.9 in Example I and 28.2 in the remaining examples. The material of lower Abbe V number is used for the middle element of the front triplet in all examples, for the front element of the rear doublet in Examples I and II, and for the middle element of the rear triplet in Examples III, IV and V.

The ratio of the prism angle of the front element of the front triplet to that of the rear element of such triplet, is 0.28 in Example I, 0.23 in Example II, 0.87 in Example III and 0.55 in Examples IV and V. The sum of such two prism angles exceeds the prism angle of the middle element of the front triplet by 22.82 in Example I, 22.85 in Example II, 22.22 in Example III, 19.19 in Example IV and 19.22 in Example V, in each case in

degrees.

In the first two examples, the prism angle of the rear element of the rear doublet exceeds that of the front element thereof by 20.93 degrees in Example I and by 21.17 degrees in Example II. In the remaining three examples, the sum of the prism angles of the outer elements of the rear triplet exceeds the prism angle of the middle element of such triplet by 18.06 degrees in Example III, by 18.17 degrees in Example IV and by 15.07 degrees in Example V.

The second portions of the various tables give data for the useful ranges of magnification of the examples, and the stops are provided to limit the adjustment to such range, since the aberration corrections are not maintained outside the range. In each case, the relationships are such that an incident ray which is an axial ray in any one position of adjustment remains an axial ray throughout the range of adjustment. Example I, with a somewhat smaller range of adjustment than the other examples, has the property that the angular movements of the two compound prisms bear an approximately linear relationship to one another. The arrangements are also such that, in each case, in the position of highest magnification, the two compound prisms are each approximately achromatic.

In the first two examples, employing a rear doublet, good correction for axial colour is maintained throughout the range of magnification, whilst in the other three examples, employing a rear triplet, not only good axial

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colour correction, but also good oblique colour correction is maintained throughout the magnification range.

The anamorphic system according to the invention is primarily intended for use in front of a main objective, with a collimating lens system in front of the anamorphic system in order to collimate the rays passing through the system. If the system is used for the projection on a cinematograph film, the film is located at the short conjugate plane on the rear side of the main objective and the system will act to broaden out the laterally compressed film undistorted proportions. If on the other hand, the system is used for photographing a broad panoramic scene on to a cinematograph film, the scene to be photographed will be in the neighbourhood of the long conjugate plane in front of the system and the film in the short conjugate plane, and the system will act to

produce on the film a laterally compressed image of the same, suitable for subsequent projection in the manner just described to produce a screen image in the original proportions of the panoramic scene.

The anamorphic system according to the invention is also suitable for use, in the manner forming the subject of the present applicants' pending British Patent Application No. 10749 of 1954 (Serial No. 747,228), in conjunction with a second similar anamorphic system whose prism generators lie at right angles to those of the first system, in cooperation with the main objective and a collimating lens system, to increase the effective angular field of the objective for wide angle work. In such case, the prisms may be fixed in position, or alternatively, the two systems may be adjustable to give variable magnifications in the two operative planes.

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Agent for the Applicants.

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765,775 COMPLETE SPECIFICATION  
3 SHEETS This drawing is a reproduction of  
the Original on a reduced scale.  
SHEET 1

FIG. 1

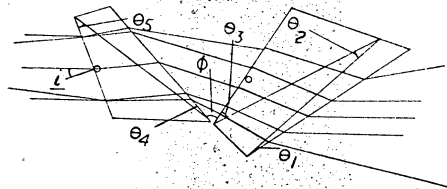


FIG. 2

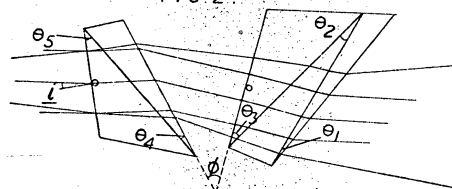
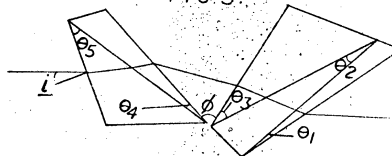
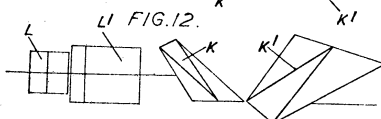
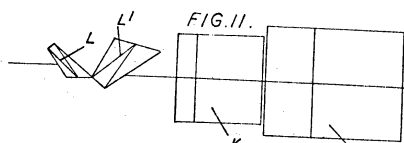
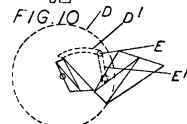
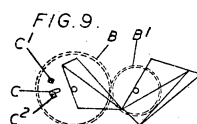
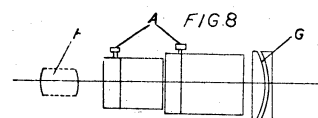
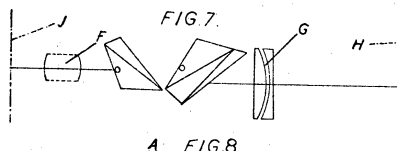
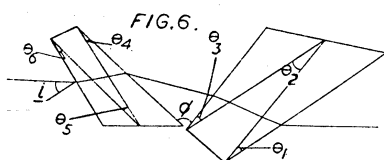
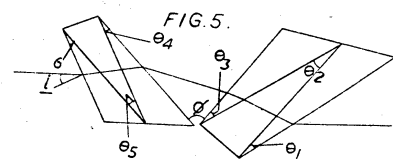
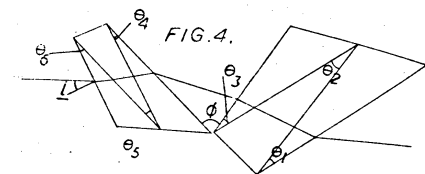


FIG. 3



765,775 COMPLETE SPECIFICATION  
3 SHEETS  
This drawing is a reproduction of  
the Original on a reduced scale.  
SHEETS 2 & 3



# PATENT SPECIFICATION 760,588



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Complete Specification Published : Nov. 7, 1956.

Index at Acceptance :—Class 97(1), B7C, J23.

## COMPLETE SPECIFICATION

### Improvements in or relating to Variable Magnification Optical Systems.

We, W. WATSON & SONS LIMITED, a British Company, of 313 High Holborn, London, W.C.1, and HAROLD HORACE HOPKINS, a British Subject, of the Company's address, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement :—

The invention relates to variable magnification optical systems of the kind (hereinafter referred to as the kind described) which may be used alone or in conjunction with a further optical system (e.g. the lens system of a camera) to produce an image of continuously variable size of an object at a fixed distance from the system. Such a system may be used for example in or with a stationary cine camera or television transmitting camera in order continuously to increase or decrease the size of the image, on the film or other image receiving device, of objects in the scene towards which the camera is directed and thereby to give the impression when the film is produced, or the television receiver is viewed, that the viewpoint approaches or recedes from objects in the scene.

Examples of variable magnification optical systems of the kind described are described and claimed in Specifications Nos. 639,610, 639,611, 639,612, 646,409, 685,945, 722,325 and 713,024.

It is an object of the invention to provide an improved variable magnification optical system of the kind described.

The invention provides a variable magnification optical system comprising two positive (convergent) lenses and a negative (divergent) lens, all arranged on a common optical axis with the two lenses spaced apart, and the negative lens between the two positive lenses and spaced from at least one of them, the lenses being movable axially and the

positive lenses being constrained to maintain a constant axial distance between them during their axial movement, and, in combination with the lenses, magnification varying means for continuously and simultaneously moving the two positive lenses and the negative lens along the optical axis relative to a stationary base or like support according to a law such that the distance from a fixed point on the base at which the image of an object at a fixed distance from the said fixed point on the base is accurately focused remains constant while the size of the said image is continuously varied during the operation of the magnification varying means, the distance between the image position for the rear one of the said positive lenses and the corresponding conjugate object position for the other of the said positive lenses being finite and not greater numerically than a small multiple of (e.g. 10 times, or more preferably 7 times) the focal length of either of the said positive lenses. This last mentioned condition ensures that the object distance for the front movable positive lens and the image distance for the rear movable positive lens are both finite, and consequently the individual magnifications produced by each of the said positive lenses change as the positions of these lenses are changed by the operation of the magnification varying means.

It will be appreciated that when the system includes one or more lenses interposed between the rear one of the said positive lenses and the final image position for the system, the said image position for that rear one of the said positive lenses will be the position of the intermediate real or virtual image formed by that rear positive lens, otherwise it will be the position of the final image for the system. Similarly, when the system includes one or more lenses interposed between the other (front) one of the said positive lenses and the actual object position the said conjugate

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object position for the front one of the said positive lenses will be the intermediate real or virtual image which acts as the effective object for that front positive lens, otherwise it will be the actual object position for the system.

Furthermore the system is preferably designed and used so that the magnifications of the two movable positive lenses are of like sign, preferably such that each movable positive lens produces an inverted image of the effective object for that lens. This preferred condition is satisfied if the object distance for the front movable positive lens is negative in sign and numerically greater than the focal length of the said front movable positive lens, and the image distance for the rear movable positive lens is positive in sign and numerically greater than the focal length of the said rear movable positive lens, an object or image distance being regarded herein as negative or positive according as the said object or image is in front of or at the rear of the lens to which it refers. When the magnifications of the two movable positive lenses are so arranged to be of like sign in any given position of the said movable positive lenses, the said magnifications change in such a manner, when the lenses are displaced as described above, that they both increase together or decrease together in numerical value (according as the said displacement of the movable positive lenses is in one direction or the other), and hence both act in the same sense so far as their effect in increasing or decreasing the size of the fixed final image is concerned. When the movable positive lenses are displaced relative to the base, by the operation of the magnification varying means, the movable negative lens is simultaneously displaced by the said magnification varying means by an amount such that the distance from an object in a fixed position relative to the base to the image of that object produced by the action of the two movable positive lenses and the movable negative lens taken together remains constant. There will be, in general, two positions of the movable negative lens for which this condition is satisfied and to distinguish between these two positions the movement of the movable negative lens relative to that of the movable positive lenses is preferably arranged such that the magnification of the movable negative lens increases or decreases numerically according as the magnifications of the movable positive lenses increase or decrease in numerical value. The individual magnifications of all the three movable lenses then simultaneously and continuously increase or decrease in numerical value as the positions of the said three movable lenses are simultaneously and continuously varied by the operation of the magnification varying

means, and this constitutes a valuable preferred feature of the invention.

The ranges of movement of the lenses are preferably such that the maximum and minimum magnifications of the system are reciprocals one of the other. This is advantageous in correcting the aberrations of the system. The two movable positive lenses preferably have equal focal lengths and the movements of the three movable lenses are preferably such that during their range of movements the position of the negative lens relative to the two positive lenses changes from near one of the positive lenses (to give one limit value of magnification) to near the other of the positive lenses (to give another limit value of magnifications, which limit value is the reciprocal of the other limit value). The focal lengths of the lenses of the system are preferably such as to give approximately equal amounts of positive and negative power in the system.

The maximum distance through which it is necessary for the negative lens to be moved has been found to depend upon the value of the said constant axial distance between the two positive lenses. It has been found that the necessary displacement of the negative lens, relative to a fixed point on the base, in one sense for small values of the constant axial distance between the two positive lenses and is in the opposite sense for suitable larger values of that constant distance. To simplify the mechanical design of the magnification varying means the value of the constant axial distance between the two positive lenses may be chosen so that the distance through which the negative lens has to be moved is at a minimum or at least is small. To satisfy other conditions, however, (e.g. correction of aberrations) it may be desirable to employ a different constant axial distance between the positive lenses and consequently to move the negative lens through a larger distance. It has been found that an increase in the value of the constant axial distance between the two positive lenses results in it being necessary to move those lenses through a smaller distance relative to the base to achieve any given range of magnification. In conjunction with any given focal length

for the negative lens, the positive lenses may have any of a range of focal lengths. An increase in the value of the focal lengths of the positive lenses enables a greater range of magnification to be achieved.

In the system of the present invention the individual magnifications of all of the three movable lenses change in one and the same direction when the magnification varying means are operated to change the magnifica-

tion of the complete system. Consequently the three lenses all contribute in the same sense the desired change in magnification.

The invention enables very large variations of magnification to be obtained without the overall length of the system being excessive.

The system may include two fixed or stationary lenses positioned on the optical axis, respectively optically before and after the three movable lenses. The stationary lenses may be both of the same sign and are preferably both positive lenses. They are preferably of equal focal length and symmetrically positioned about the mid-position of the three movable lenses. The inclusion of such a pair of fixed positive lenses increases the overall length of the system but facilitates the correction of aberrations. The effect of the fixed lenses is to increase the angle of rays of the axial pencil, thereby affording the possibility of an increased re-entrant aperture (lower F number) with the same linear lens diameters. In this case by arranging that the power of the rear fixed positive lens is greater than that of the front fixed positive lens the equivalent focal length of the system is reduced.

The ranges of movement of the movable lenses are preferably such that at one, or each, limit of their movements the movable negative lens lies very close to one of the movable positive lenses, the criterion of closeness being that the principal planes of the movable negative lens and the adjacent movable positive lens shall have a separation which is very small in comparison with their focal lengths. A fixed or normally stationary lens, preferably a negative lens, may be positioned optically in front of the movable lenses and may be adjustable along the axis to focus the system for objects at various distances from the base. This normally stationary lens may constitute one of the aforesaid two fixed or stationary lenses or it may be provided instead of those two lenses. When the normally stationary lens is negative it may be of such focal length that when it is focused for an infinite object distance the position of the normally stationary negative lens is such that it just permits the full range of movement of the movable positive lenses, with a clearance determined only by practical considerations. A diaphragm stop for the system may be placed in contact with the movable negative lens and when the whole system is working in its wide angle position the separation between the normally stationary negative lens and the front one of the movable positive lenses may be of the order of the focal length of the normally stationary negative lens. If the movable negative lens is in contact with the positive lens nearest to the normally stationary negative lens, then the stop

position so determined constitutes the exit pupil for the normally stationary negative lens and, in consequence, the distance of the entrance pupil for this lens will be at a distance rearwardly of it of the order of half its focal length, and this means that the incidence heights for the principal rays are small for a lens of this kind and hence permit the use of a large angle field. This is of importance in correcting the aberrations.

A specific example of a system embodying the invention will now be described by way of example and with reference to the drawing accompanying the Provisional Specification, in which the single Figure, Figure 1, is a diagrammatic longitudinal section showing the optical arrangement of the system, and the drawings accompanying the present Specification, in which:—

Figure 2 is a longitudinal sectional view of the system, taken on the line 2—2 of Figure 3;

Figure 3 is a sectional view taken on the line 3—3 of Figure 2;

Figure 4 is a graph showing the movement of the movable negative lens relative to the base; and

Figure 5 shows ray paths through the system.

In this example the system comprises a normally stationary negative lens 11, two movable positive lenses 12, 13 and a movable negative lens 14. An image receiver, e.g. a film, is placed at 15. The movable positive lenses 12, 13 are rigidly mounted on a carriage 16, which maintains them at a constant axial distance apart.

The lenses are housed in a casing 17 having a base 18. The carriage 16 has wheels 19 which run on rails 21 secured to the casing 17, and the carriage 16 is propelled along the rails 21 by a drum 22 which has its ends attached to the carriage at 23, 24. The wire 22 passes over guide pulleys 25, 26. The drum may be rotated in either direction by a control knob 27, thereby to drive the carriage along the rails and so move axially the two positive lenses 12, 13.

A block 31 secured rigidly to the base 18 provides a stationary bearing for a vertical shaft 32 carrying for rotation together with it a gear wheel 33 and a cam 34. The gear wheel 33 meshes with a rack 35 carried by the carriage 16 and rigidly suspended beneath it by brackets 36. Thus, as the carriage moves along the rails the engagement between the gear wheel 33 and the rack 35 causes the cam 34 to rotate, its angular position at any instant being determined by the position of the carriage along the length of the rails.

The movable negative lens 14 is carried by a slide 37 which is guided for movement

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parallel to the axial direction of the lenses by suitable shaped parts 38 formed at the upper end of the block 31. The slide 37 has a downwardly projecting pin 39 which engages with the periphery of the cam 34, the slide 37 being urged by a spring (not shown) to maintain the pin 39 in contact with the cam. As the cam rotates the slide 37, and consequently the negative lens 14, are moved axially in accordance with the required law. Thus manual rotation of the control knob 27 moves the three lenses 12, 13, 14 in the required manner.

The law of movement of the movable lenses in this example is as indicated in the following table which shows the variation in the axial distances  $d_1$ ,  $d_2$ ,  $d_3$  and  $d_1+d_2$ :

F	$d_1$	$d_2$	$d_3$	$d_1+d_2$
64.746	0.3132	8.0	0.0	17.352
53.229	0.6528	7.5	0.5	17.014
43.122	1.0363	7.0	1.0	16.631
34.395	1.4684	6.5	1.5	16.198
27.000	1.9524	6.0	2.0	15.715
20.868	2.4883	5.5	2.5	15.178
15.9087	3.072	5.0	3.0	14.595
12.0000	3.692	4.5	3.5	13.974
9.0000	4.333	4.0	4.0	13.333
6.7500	4.974	3.5	4.5	12.692
5.0916	5.595	3.0	5.0	12.072
3.8815	6.178	2.5	5.5	11.4883
3.0000	6.715	2.0	6.0	10.9524
2.3549	7.198	1.5	6.5	10.4684
1.87839	7.631	1.0	7.0	10.0363
1.52172	8.014	0.5	7.5	9.6528
1.25100	8.352	0.0	8.0	9.3132

The lenses have the following focal lengths:—

Lens	Focal Length
11	-9
12	+5
13	+5
14	-2

The above dimensions are expressed in inches.

The first table given above includes the value of the focal length of system for each of the listed positions in the movements of movable lenses. It will be seen that the ratio of the maximum to the minimum focal length (and consequently the ratio of the maximum to the minimum magnification) is about 50 : 1. The overall length of the system is only of the order of one third of the maximum focal length thereof.

It may be seen from the above table that in this example the movement of the movable negative lens relative to a fixed point on the base, which movement is determined by the variation in the numerical sum of the distances  $d_1$  and  $d_2$  is small. The variation

of the sum ( $d_1+d_2$ ) with the distance  $d_1$  is shown in the above first table and is also shown graphically in Figure 4. That data defines the shape of the cam 34.

Figure 5 shows the paths of rays 41 which reach the system, parallel to the axis, from the object which in this example is at infinity i.e. a very large distance away, and a ray 42 from the object, which ray reaches the system at an angle of about 5 degrees to the axis.

The lens 11 forms a virtual image at its focus 43 and that virtual image serves as the effective object for the front positive lens 12. The axial distance between the point 43 and the image receiver 15 is 34.67 inches, i.e. just under seven times the focal length of each of the positive lenses 12, 13.

The lenses are shown merely diagrammatically in the drawings and the distances, given in the above first table are calculated from the simplified theory of thin lenses. The lenses are each individually corrected for chromatic aberrations and each of them may comprise two or more component lenses cemented together or spaced apart by a fixed distance or having a combination of cementing and fixed spacing.

The field curvature may be readily made small as the absolute powers of the lenses have an algebraic sum which is small. As the changes in magnification of the complete system are contributed to substantially equally by the three movable lenses respectively the correction of the other aberrations is facilitated.

The system of this example may be employed in conjunction with a television transmitting camera, a cine camera or the like but it may alternatively be employed, for example, as a variable focal length projection lens for a film projector.

The invention is not restricted to the details of the foregoing example. For instance the three movable lenses may be employed alone, or with a pair of stationary positive or negative lenses optically before and after them, to provide a symmetrical system of variable power working about a mean magnification of minus 1, which system is suitable for lenses of the kind known as process lenses.

What we claim is:—

1. A variable magnification optical system comprising two positive (convergent) lenses and a negative (divergent) lens, all arranged on a common optical axis with the two positive lenses spaced apart, and the negative lens between the two positive lenses and spaced from at least one of them, the said lenses being movable axially and the positive lenses being constrained to maintain a constant axial distance between them during their axial movement, and, in combination with the lenses, magnification varying means for continuously and simultaneously moving the two positive lenses and the negative lens along the optical axis relative to a stationary base or like support according to a law such that the distance from a fixed point on the base at which the image of an object at a fixed distance from the said fixed point on the base is accurately focused remains constant while the size of the said image is continuously varied during the operation of the magnification varying means, the distance between the image position for the rear one of the said positive lenses and the corresponding conjugate object position for the other of the said positive lenses being finite and not greater numerically than a small multiple of the focal length of either of the said positive lenses.

2. A variable magnification optical system as claimed in Claim 1, in which the object distance for the front one of the said positive lenses is negative in sign (as hereinbefore defined) and numerically greater than the focal length of that rear positive lens, and the image distance for the rear one of the said positive lenses is positive in sign (as hereinbefore defined) and numerically greater than the focal length of that front positive lens.

3. A variable magnification optical system as claimed in Claim 1 or Claim 2, in which the movement of said negative lens relative to that of the said positive lenses is such that the magnification of the said negative lens increases or decreases numerically according as the magnifications of the said positive lenses increase or decrease in numerical value.

4. A variable magnification optical system as claimed in any one of the preceding claims, in which the ranges of movement of the said three lenses are such that the maximum and minimum magnification of the system are reciprocals one of the other.

5. A variable magnification optical system as claimed in any one of the preceding claims, in which the said two positive lenses have equal focal lengths.

6. A variable magnification optical system as claimed in Claims 4 and 5 in which the movements of the said three lenses are such that during their range of movements the position of the negative lens relative to the two positive lenses changes from near one of the positive lenses (to give one limit value of magnification) to near the other of the positive lenses (to give another limit value of magnification), which limit value is the reciprocal of the other limit.

7. A variable magnification optical system as claimed in Claim 6, in which the ranges of movement of the movable lenses are such that at one, or each limit of their movements the said negative lens lies very close to one of the said positive lenses, the criterion of closeness being that the principal planes of the said negative lens and the adjacent positive lens have a separation which is very small in comparison with their focal lengths.

8. A variable magnification optical system as claimed in any one of the preceding claims, including two fixed or stationary lenses positioned on the optical axis, respectively optically before and after the said three movable lenses.

9. A variable magnification optical system as claimed in Claim 8, in which the stationary lenses are both positive lenses, are of equal focal length and are symmetrically positioned about the mid-position of the three movable lenses.

10. A variable magnification optical system as claimed in any one of Claims 1 to 7, in which a fixed or stationary lens is positioned optically in front of the three movable lenses.

11. A variable magnification optical system as claimed in Claim 10, in which the said fixed or stationary lens is a negative lens.

12. A variable magnification optical system as claimed in Claim 10 or Claim 11, in which the said stationary lens is adjustable along the axis to focus the system for objects at various distances from the base.

13. A variable magnification optical system as claimed in Claim 11 or Claim 12, in which the said stationary lens is of such focal length that when it is focused for an infinite object distance the position of that stationary lens is such that it just permits the full range of movement of the movable positive lenses.

14. A variable magnification optical system substantially as hereinbefore described with reference to, and illustrated in, the drawing accompanying the Provisional Specification and the drawings accompanying the present Specification.

BOULT, WADE & TENNANT.

111 & 112, Hatton Garden, London, E.C.1.  
Chartered Patent Agents.

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## PROVISIONAL SPECIFICATION

## Improvements in or relating to Variable Magnification Optical Systems.

We, W. WATSON & SONS LIMITED, a British Company, of 313 High Holborn, London, W.C.1, and HAROLD HORACE HOPKINS, a British Subject, of the Company's address, do hereby declare this invention to be described in the following statement:—

The invention relates to variable magnification optical systems of the kind (hereinafter referred to as the kind described) may be used alone or in conjunction with a further optical system (e.g. the lens system of a camera) to produce an image of continuously variable size of an object at a fixed distance from the system. Such a system may be used for example in or with a stationary cine camera or television transmitting camera in order continuously to increase or decrease the size of the image, on the film or other image receiving device, of objects in the scene towards which the camera is directed and thereby to give the impression when the film is projected, or the television receiver is viewed, that the view-point approaches or recedes from objects in the scene.

Examples of variable magnification optical systems of the kind described are described and claimed in Specifications Nos. 639,610, 639,611, 639,612, 646,409, 685,945 and 21425/51.

It is an object of the invention to provide an improved variable magnification optical system of the kind described.

The invention provides, in one of its aspects, a variable magnification optical system comprising two movable positive (convergent) lenses and movable negative (divergent) lens, all arranged on a common optical axis with the two positive lenses spaced apart, and the negative lens between the two positive lenses and spaced from at least one of them, the lenses being movable axially and the positive lenses being constrained to maintain a constant axial distance between them during their axial movement, and in combination with the lenses, magnification varying means for continuously and simultaneously moving the two positive lenses and the negative lens along the optical axis relative to a stationary base or like support according to a law such that the distance from a fixed point on the base at which the image of an object at a fixed distance from the said point on the base is accurately focused remains constant while the size of the said image is continuously varied during the operation of the magnifi-

cation varying means, the distance between the said fixed object point and the constant image so produced being finite and not greater numerically than a small multiple of the focal length of either of the said movable positive (convergent) lenses. This condition ensures that the object distance for the front movable positive lens and the image distance for the rear movable positive lens are both finite, and consequently the individual magnifications produced by each of the said movable positive lenses change as the positions of these lenses are changed by the operation of the magnification varying means. Furthermore the magnifications of the two movable positive lenses are arranged to be of like sign preferably such that each movable positive lens produces an inverted image of the object for that lens. This preferred condition is satisfied if the object distance for the front movable positive lens is negative in sign and numerically greater than the focal length of the said front movable positive lens, and the image distance for the rear movable positive lens is positive in sign and numerically greater than the focal length of the said rear positive movable lens, an object or image distance being regarded as negative or positive according as the said object or image is in front of or at the rear of the lens to which it refers. When the magnifications of the two movable positive lenses are so arranged to be of like sign in any given position of the said movable positive lenses, the said magnifications change in such a manner, when those lenses are displaced as described above, that they both increase together or decrease together in numerical value (according as the said displacement of the movable positive lenses is in one direction or the other), and hence both act in the same sense so far as their effect in increasing or decreasing the size of the fixed final image is concerned. When the movable positive lenses are displaced in one direction or the other, the magnification varying means, the movable negative lens is simultaneously displaced by the said magnification varying means by an amount such that the distance from an object in a fixed position relative to the base to the image of that object produced by the action of the two movable positive lenses and the movable negative lens taken together remains constant. There will be, in general, two positions of the movable negative lens for which this condition is satisfied and to distinguish between these two positions the

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movement of the movable negative lens relative to that of the movable positive lenses is preferably arranged such that the magnification of the movable negative lens increases or decreases numerically according as the magnification of the movable positive lenses increase or decrease in numerical value. The individual magnifications of all the three movable lenses then simultaneously and continuously increase or decrease in numerical value as the positions of the said three movable lenses are simultaneously and continuously varied by the operation of the magnification varying means, and this constitutes a valuable feature of the invention.

The ranges of movement of the lenses are preferably such that the maximum and minimum magnifications of the system are reciprocals one of the other. This is advantageous in correcting the aberrations of the system. The two movable positive lenses preferably have equal focal lengths and the movements of the three movable lenses are preferably such that during their range of movements the position of the negative lens relative to the two positive lenses changes from near one of the positive lenses (to give one limit value of magnification) to near the other of the positive lenses (to give another limit value of magnification, which limit value is reciprocal of the other limit value). The focal lengths of the lenses of the systems are preferably such as to give approximately equal amounts of positive and negative power in the system.

The maximum distance through which it is necessary for the negative lens to be moved has been found to depend upon the value of the said constant axial distance between the two positive lenses. It has been found that the necessary displacement of the negative lens, relative to a fixed point on the base, is in one sense for small values of the constant axial distance between the two positive lenses and is in the opposite sense for suitable larger values of that constant distance. To simplify the mechanical design of the magnification varying means the value of the constant axial distance between the two positive lenses may be chosen so that the distance through which the negative lens has to be moved is at a minimum or at least is small. To satisfy other conditions, however, (e.g. correction of aberrations) it may be desirable to employ a different constant axial distance between the positive lenses and consequently to move the negative lens through a larger distance. It has been found that an increase in the value of the constant axial distance between the two positive lenses results in it being necessary to move those lenses through a smaller distance relative to the base to achieve any given range of magnification, and that, alternatively, movement of the positive lenses

through the same distance provides a greater range of magnification.

In conjunction with any given focal length for the negative lens, the positive lenses may have any of a range of focal lengths. An increase in the value of the focal lengths of the positive lenses enables a greater range of magnification to be achieved.

In the system of the present invention the individual magnifications of all of the three lenses change in one and the same direction when the magnification varying means are operated to change the magnification of the complete system. Consequently the three lenses all contribute in the same sense the desired change in magnification.

The invention enables very large variations of magnification to be obtained without the overall length of the system being excessive.

The system may include two fixed or stationary lenses positioned respectively on the optical axis, respectively optically before and after the three movable lenses. The fixed lenses may be both the same sign and are preferably both positive lenses. They are preferably of equal focal length and symmetrically positioned about the mid position of the three movable lenses. The inclusion of such a pair of fixed positive lenses increases the overall length of the system but facilitates the correction of aberrations. The effect of the fixed lenses is to increase the angle of rays of the axial pencil, thereby affording the possibility of an increased relative aperture (lower F number) with the same linear lens diameters. In this case by arranging that the power of the rear fixed positive lens is greater than that of the front fixed positive lens the equivalent focal length of the system is reduced by a factor which is greater than the reduction of the overall length and, in consequence, as stated above the advantage of great reduction of overall length is lost. It remains, however, that when a large range of magnification is contemplated that advantage is obtainable and this is of considerable advantage to the designer.

The ranges of movement of the movable lenses are preferably such that at one, or each, limit of their movements the movable negative lens lies very close to one of the movable positive lens, the criterion of closeness being that the principal planes of the movable negative lens and the adjacent movable positive lens shall have a separation which is very small in comparison with their focal lengths. A fixed or normally stationary lens, preferably a negative lens, may be positioned optically in front of the movable lenses and may be adjustable along the axis to focus the system for objects at various distances from the base. The normally stationary negative lens may be of such

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8 focal length that when it is focused for an  
infinite object the position of the normally  
stationary negative lens is such that it just  
permits the full range of movement of the  
movable positive lenses, with a clearance  
determined only by practical considerations.  
A diaphragm stop for the system may be  
placed in contact with the movable negative  
lens and when the whole system is working  
in its wide angle position the separation be-  
tween the normally stationary negative lens  
and the front one of the movable positive  
lenses may be of the order of the focal  
length of the normally stationary negative  
lens. If the movable negative lens is in con-  
tact with the positive lens nearest to the  
normally stationary negative lens, then the  
stop position so determined constitutes the  
exit pupil for the normally stationary nega-  
tive lens and, in consequence, the distance  
of the entrance pupil for this lens will be at  
a distance rearwardly of it of the order of  
half its focal length, and this means that the  
incidence heights for the principal rays are  
small for a lens of this kind and hence per-  
mit the use of a large angle field. This is  
of importance in correcting the aberrations.  
A specific example of a system embody-  
ing the invention will now be described by  
way of example and with reference to the  
accompanying drawing, which is a diagram-  
matic longitudinal section through the  
system.

35 In this example the system comprises a  
normally stationary negative lens 11, two  
movable positive lenses 12, 13 and a mov-  
able negative lens 14. An image receiver,  
e.g. a film, is placed at 15. The movable  
positive lenses 12, 13 are mounted in a cell or  
carrier, indicated diagrammatically at 16,  
which maintains them at a constant axial  
distance apart.

45 The law of movement of the movable  
lenses in this example is as indicated in the  
following table which shows the variation  
in the axial distances  $d_1$ ,  $d_2$ ,  $d_3$  and  $d_4$ :

F	$d_1$	$d_2$	$d_3$	$d_4$
64.746	0.3132	8.0	0.0	17.352
53.229	0.6328	7.5	0.5	17.014
43.122	1.0363	7.0	1.0	16.631
34.395	1.4684	6.5	1.5	16.198
27.000	1.9524	6.0	2.0	15.715
20.868	2.4883	5.5	2.5	15.178
15.987	3.072	5.0	3.0	14.595
12.0000	3.692	4.5	3.5	13.974
9.0000	4.333	4.0	4.0	13.333
6.7500	4.974	3.5	4.5	12.692
5.0916	5.595	3.0	5.0	12.072
3.8815	6.178	2.5	5.5	11.483
3.0000	6.715	2.0	6.0	10.954
2.3549	7.198	1.5	6.5	10.4684
1.87839	7.631	1.0	7.0	10.0363
1.52172	8.014	0.5	7.5	9.6528
1.25100	8.352	0.0	8.0	9.3132

The lenses have, the following focal  
lengths:

Lens	Focal Length
11	9
12	5
13	5
14	2

The above dimensions are expressed in  
inches.

75 The first table given above includes the  
value of the focal length of system for each  
of the listed positions in the movements of  
movable lenses. It will be seen that the  
ratio of the maximum to the minimum focal  
length (and consequently the ratio of the  
maximum to the minimum magnification) is  
about 50 : 1. The overall length of the  
system is only of the order of one third of  
the maximum focal length thereof.

85 The necessary movements are imparted to  
the movable lenses by any convenient  
mechanical means, such as appropriately  
shaped cams operated by a single control  
member.

90 It may be seen from the above table that  
in this example the movement of the mov-  
able negative lens relative to a fixed point on  
the base, which movement is determined by  
the variation in the numerical sum of the  
distances  $d_1$  and  $d_4$  is small.

95 The lenses are shown merely diagram-  
matically in the drawing and the distances  
given in the above first table are calculated  
from the simplified theory of thin lenses.  
The lenses are each individually corrected  
for chromatic aberrations and each of them  
may comprise two or more component lenses  
cemented together or spaced apart by a  
fixed distance or having a combination of  
cementing and fixed spacing.

105 The field curvature may be readily made  
small as the absolute powers of the lenses  
have an algebraic sum which is small. As  
the changes in magnification of the complete  
system are contributed to substantially  
equally by the three movable lenses respec-  
tively the correction of the other aberrations  
is facilitated.

115 The system, of this example may be em-  
ployed in conjunction with a television trans-  
mitting camera, a cine camera or the like but  
it may alternatively be employed, for  
example, as a variable focal length projec-  
tion lens for a film projector.

120 The invention is not restricted to the de-  
tails of the foregoing example. For instance  
the three movable lenses may be employed  
alone, or with a pair of stationary positive  
or negative lenses optically before and after  
them, to provide a symmetrical system of

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variable power working about a mean  
magnification of minus 1, which system is  
suitable for lenses of the kind known as pro-  
cess lenses.

5 The system may include any relevant fea-

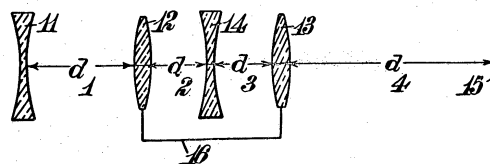
tures described in any of the hereinbefore  
mentioned Specifications.  
BOULT, WADE & TENNANT,  
111 & 112, Hatton Garden, London, E.C.1.  
Chartered Patent Agents.

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760588  
1 SHEET

PROVISIONAL SPECIFICATION  
This drawing is a reproduction of  
the Original on a reduced scale

*Fig. 1.*



760588 COMPLETE SPECIFICATION  
2 SHEETS  
This drawing is a reproduction of  
the Original on a reduced scale  
Sheets 1 & 2

Fig. 2.

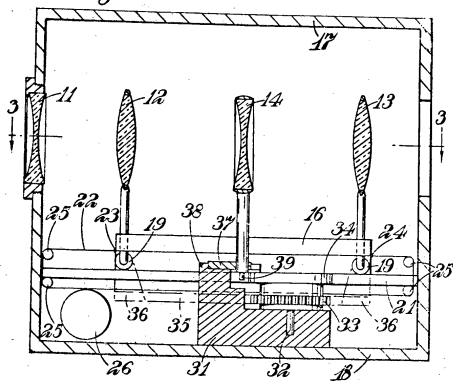


Fig. 5.

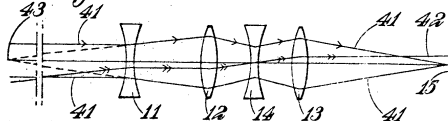


Fig. 3.

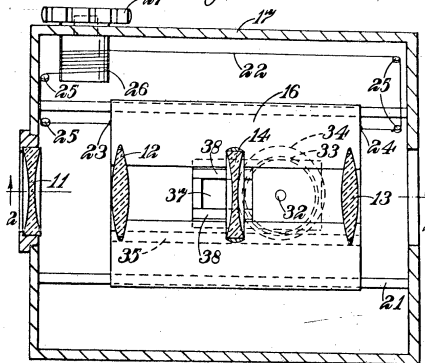
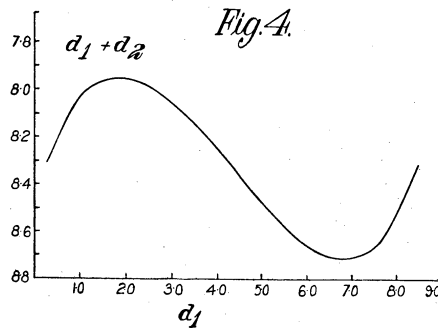


Fig. 4.



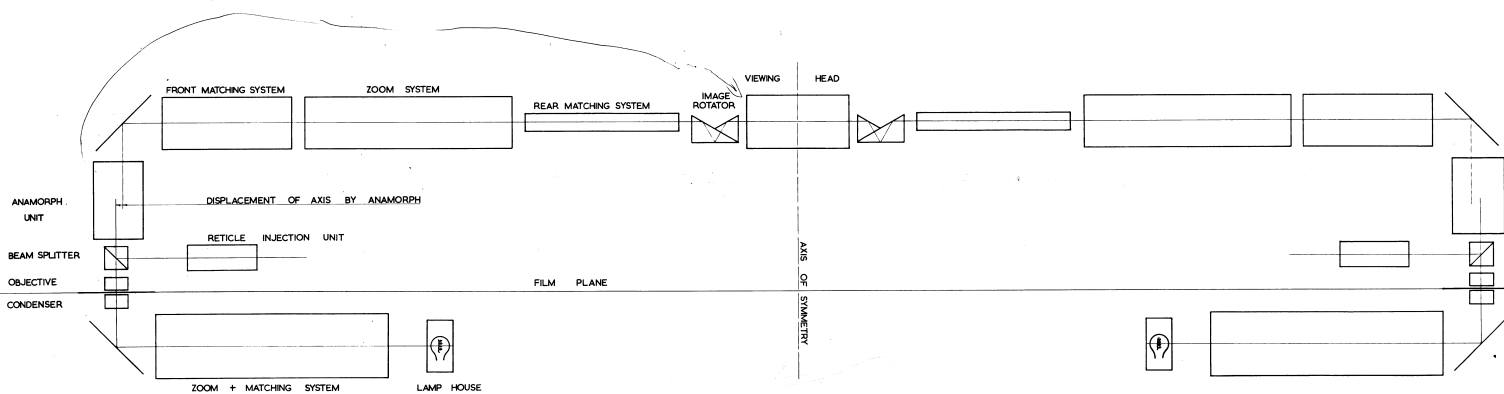
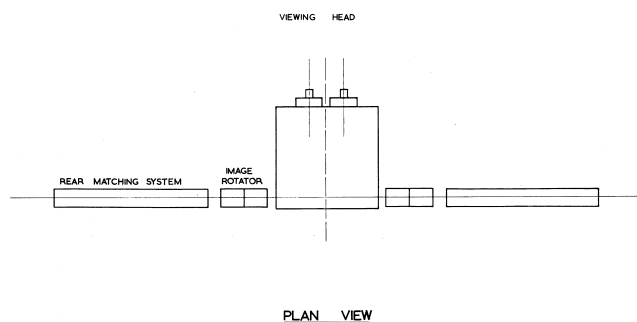
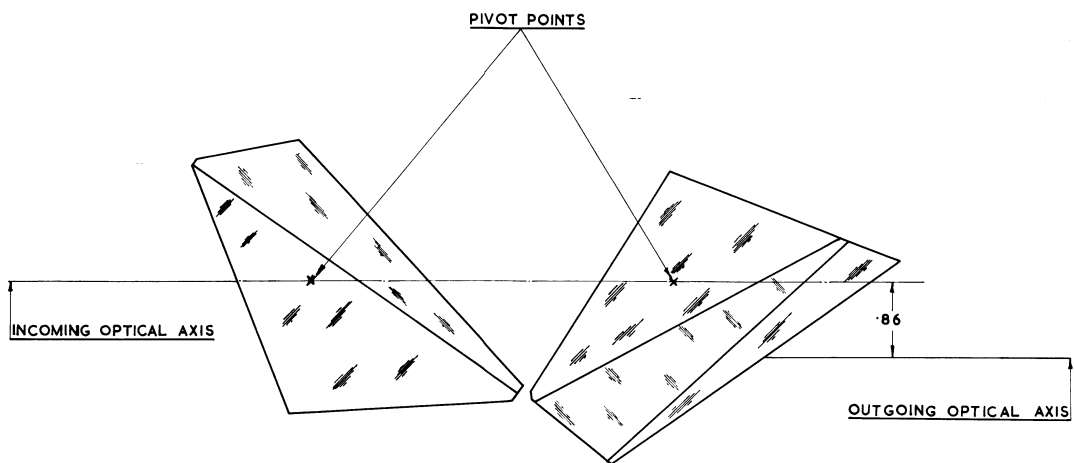


FIGURE 1 BLOCK DIAGRAM SHOWING GENERAL LAY OUT.

N.R.I. ZOOM STEREO VIEWER FEASIBILITY STUDY

RANK TAYLOR-HOBSON VARIABLE ANAMORPHOTIC SYSTEM



W. WATSON & SON LTD.  
SCALE 1:1  
BASED ON BRIT. PATENT 765775  
FIGURE 2

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ZOOM STEREO VIEWER FEASIBILITY STUDY

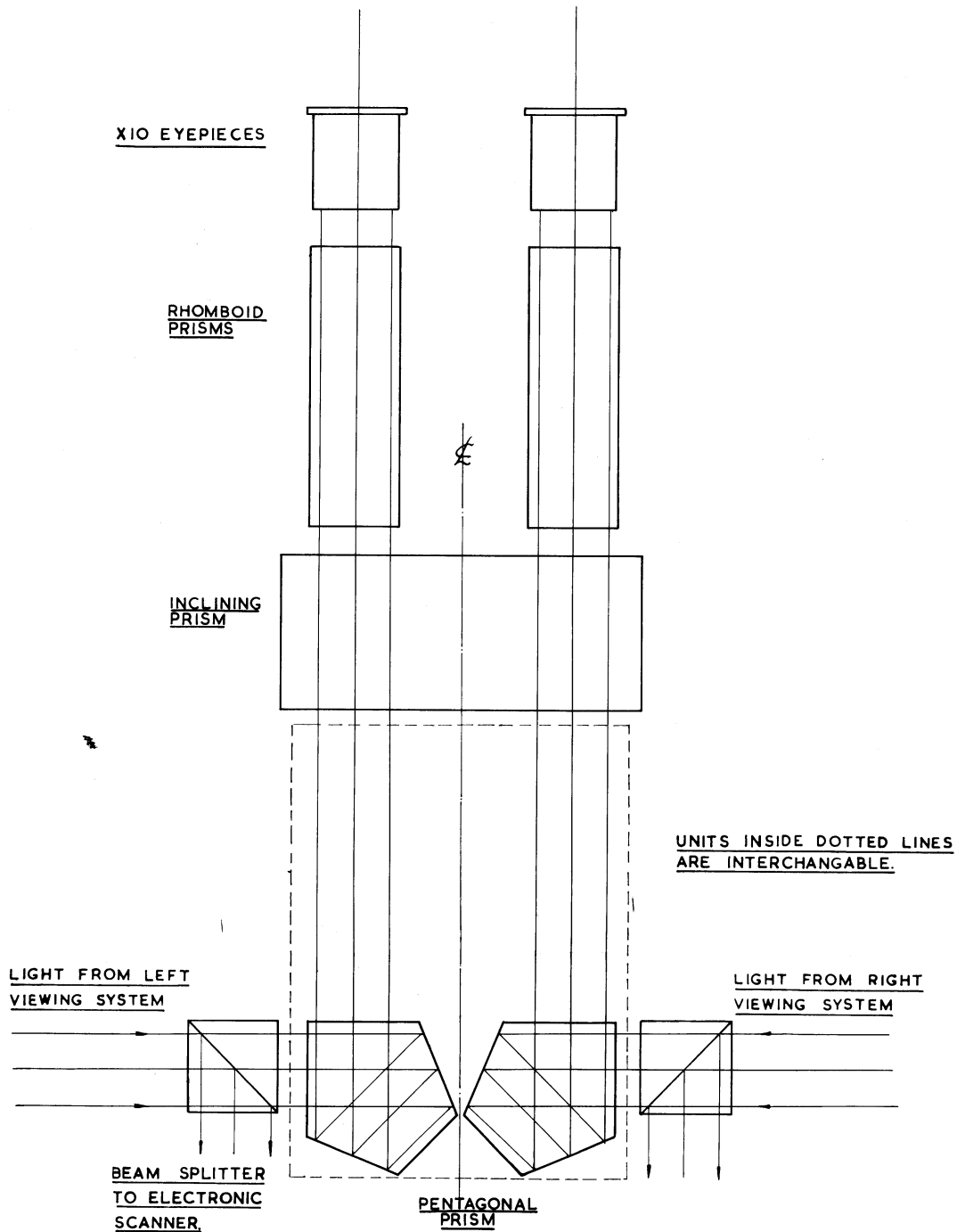
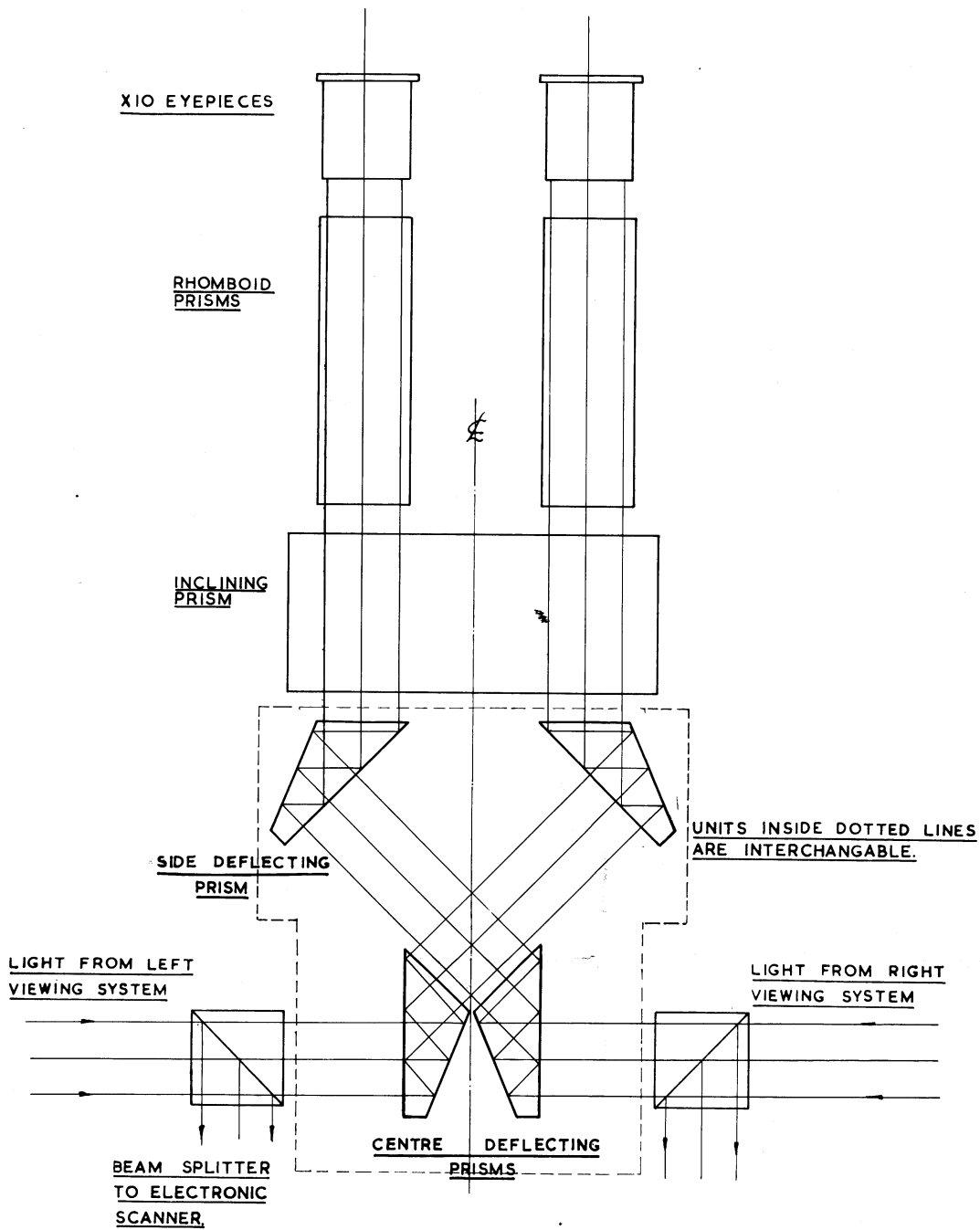


FIGURE 3a: VIEWING HEAD  
PLAN VIEW OF SWITCHING SYSTEM.  
DIRECT STEREOSCOPIC VISION. (OUTPUT  
UNITS IN DEVELOPED VIEW.)

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# **ZOOM STEREO VIEWER FEASIBILITY STUDY**

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**FIGURE 3b: VIEWING HEAD  
PLAN VIEW OF SWITCHING SYSTEM  
REVERSED STEREOSCOPIC VISION  
(OUTPUT UNITS IN DEVELOPED  
PLAN VIEW)**

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# ZOOM STEREO VIEWER FEASIBILITY STUDY

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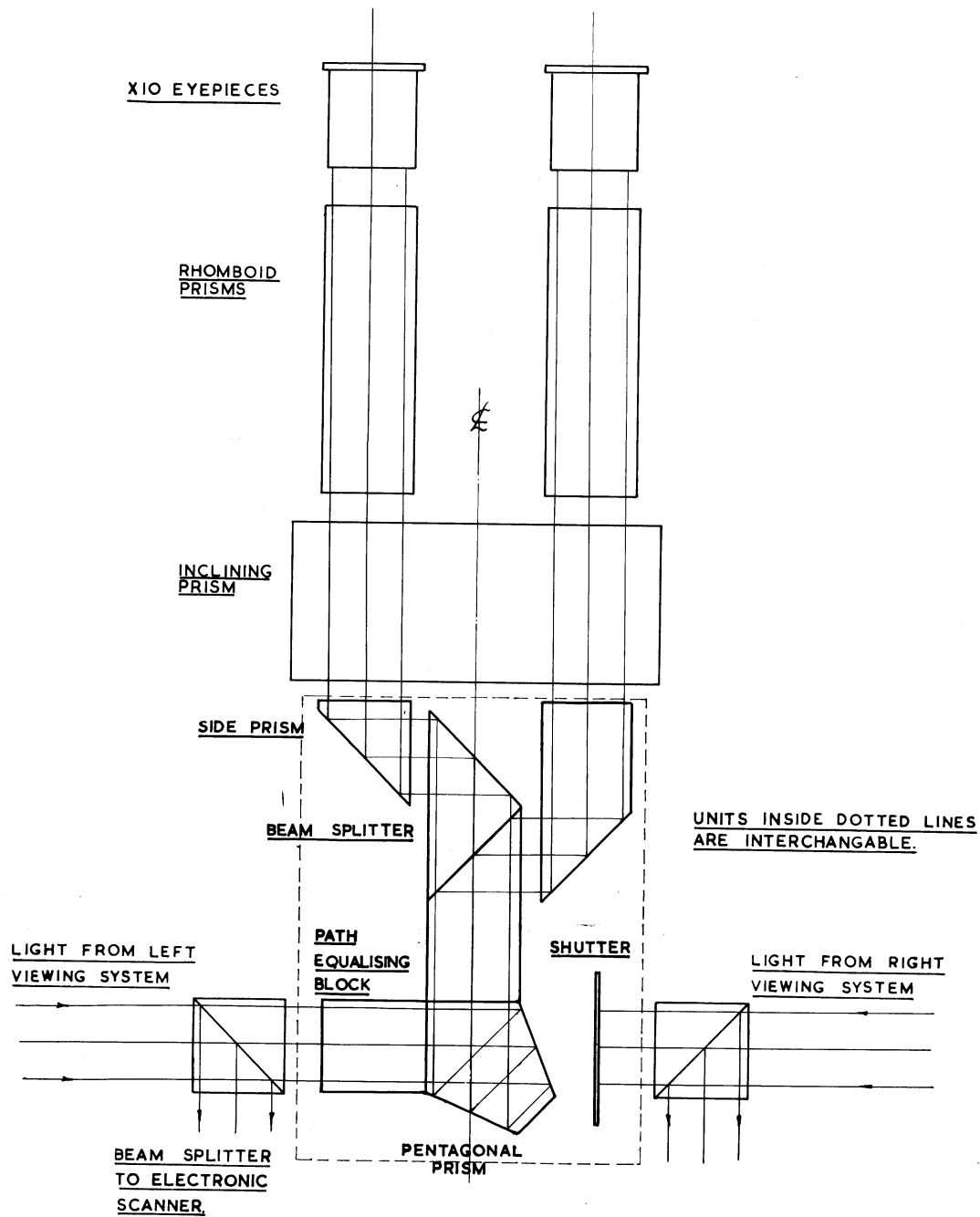


FIGURE 3c: VIEWING HEAD  
PLAN VIEW OF SWITCHING SYSTEM  
BINOCULAR OBSERVATION OF LEFT FILM  
(OUTPUT UNITS IN DEVELOPED PLAN VIEW)

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## ZOOM STEREO VIEWER FEASIBILITY STUDY

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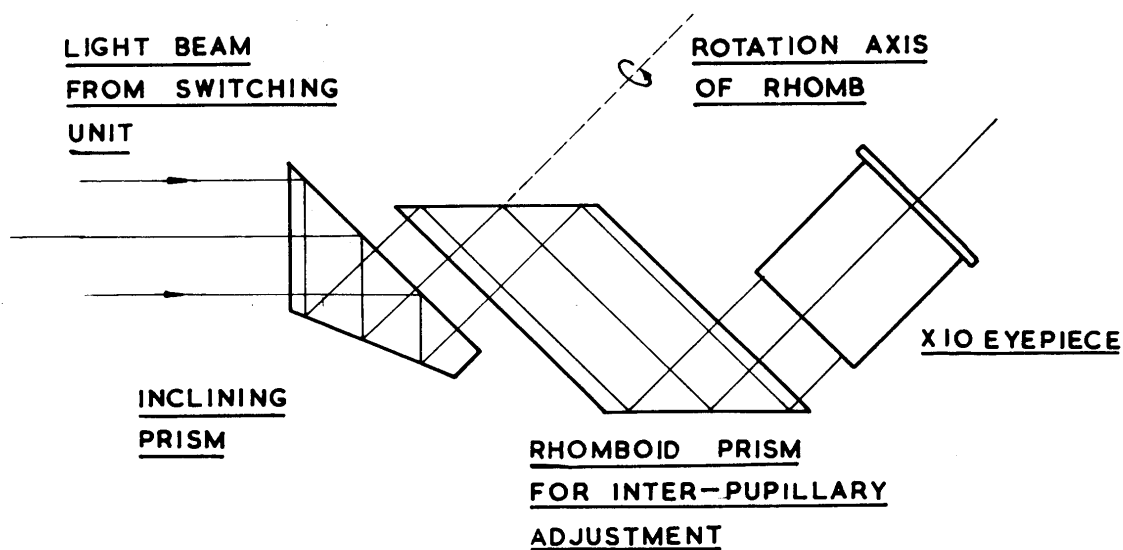


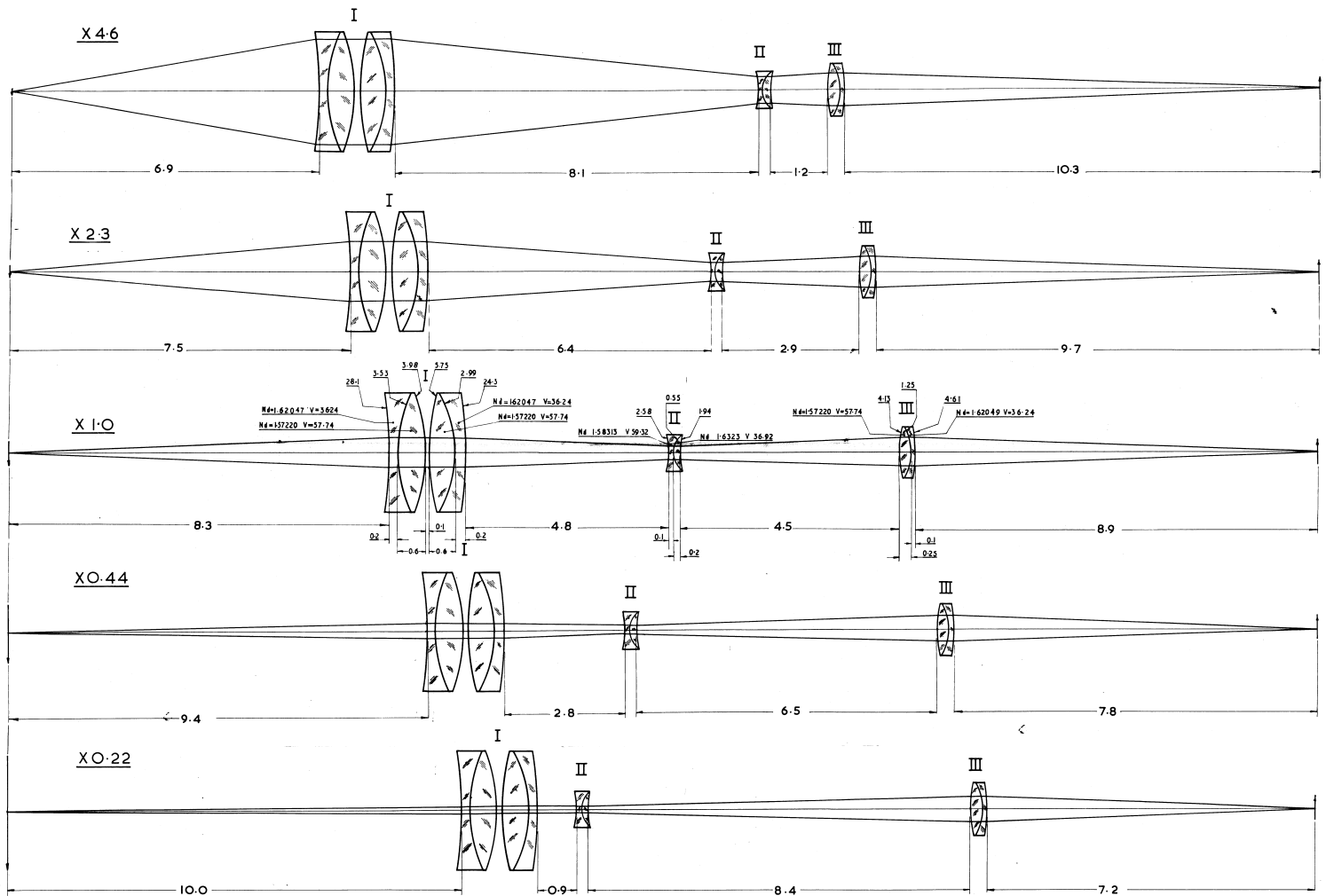
FIGURE 3a : VIEWING HEAD  
SIDWAYS SECTIONAL VIEW OF  
OUTPUT UNITS



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# ZOOM VIEWING SYSTEM FEASIBILITY STUDY

ZOOM RATIO 21:1



SURFACE RADII & OTHER DIMENSIONS IN INCHES

$N_d$  REFRACTIVE INDEX  
AT 5876 Å  
 $V = \frac{N_d - 1}{N_F - N_C}$

FIGURE 4